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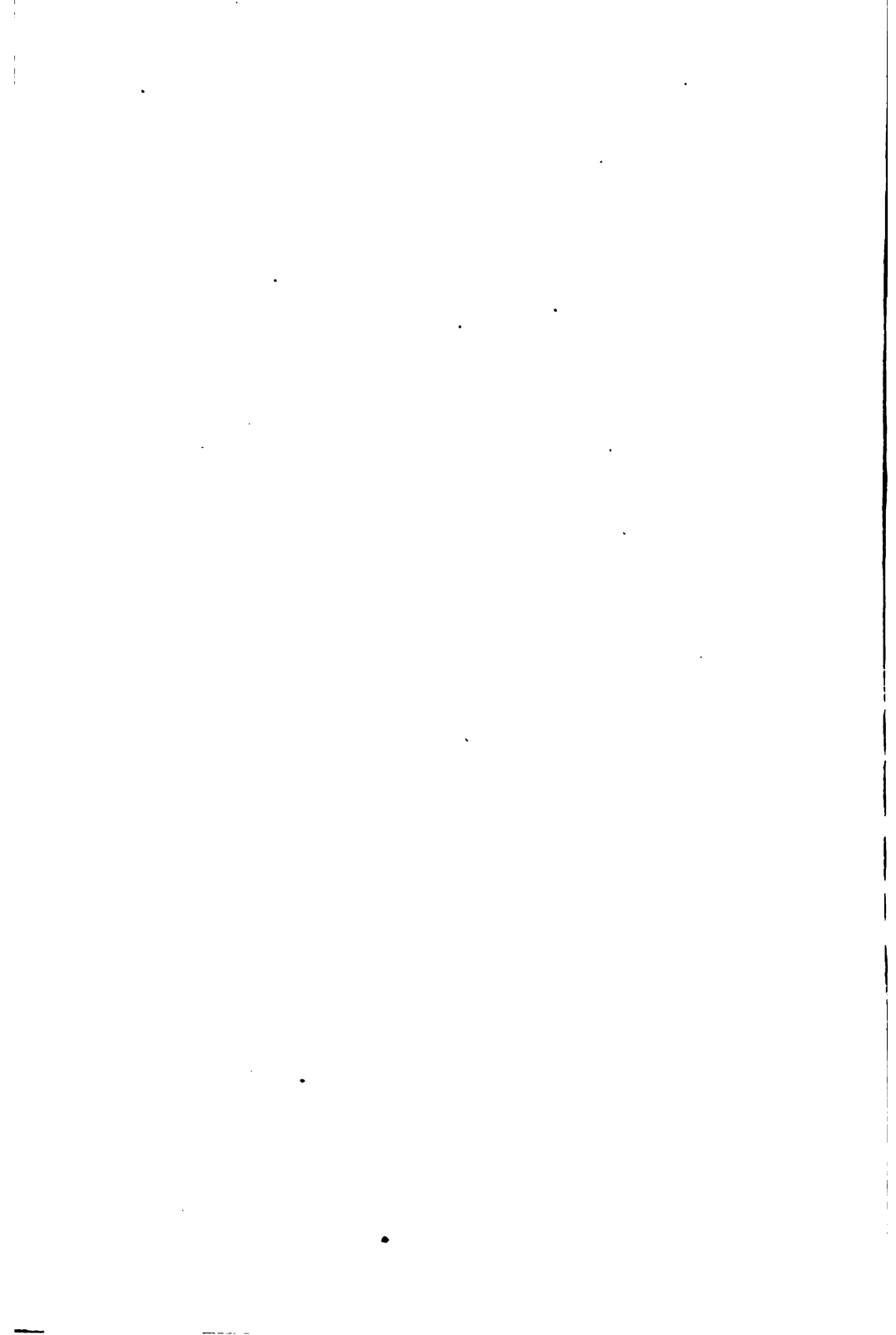






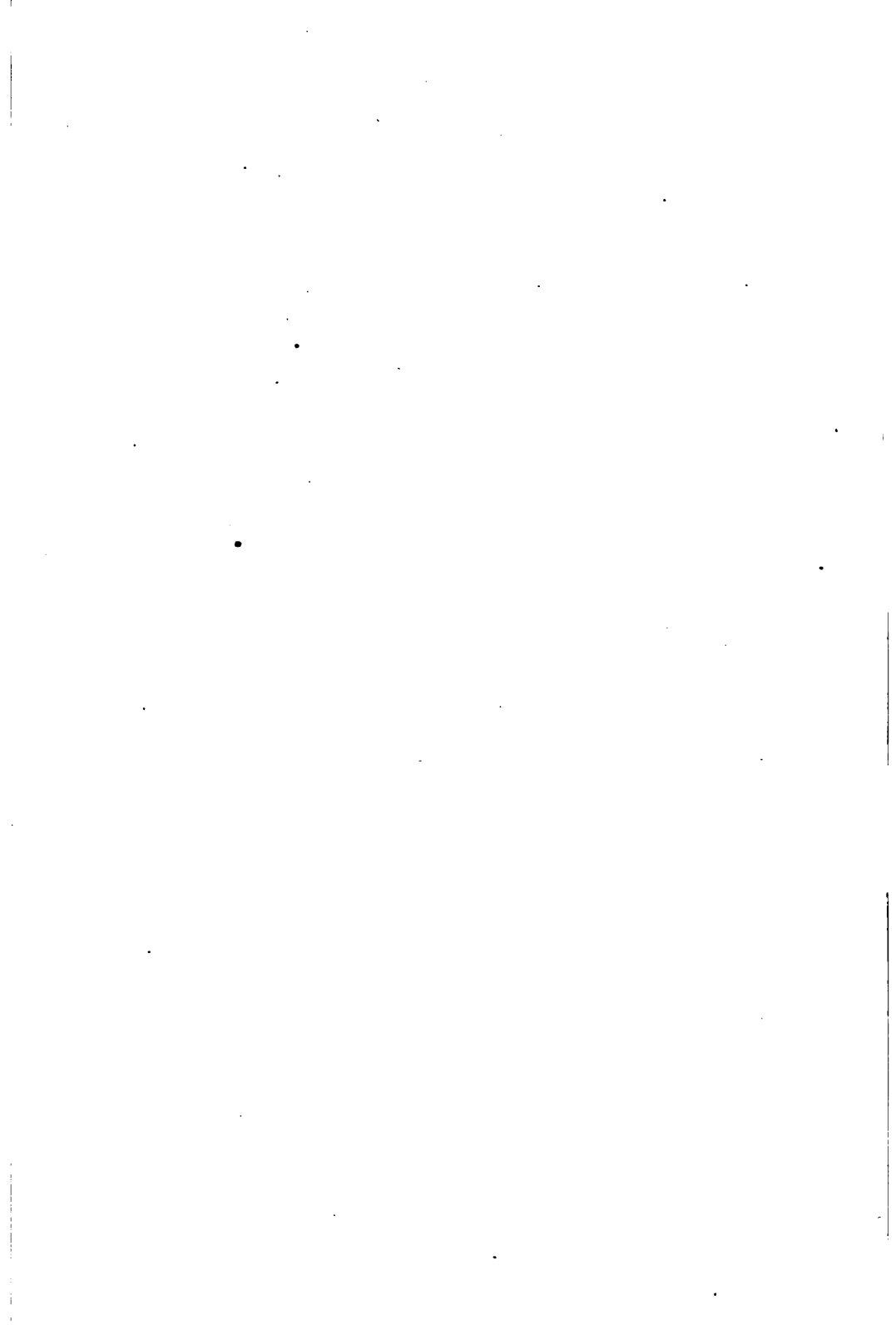
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John Howard  
u.s.a.





LECTURES  
ON  
EXPLOSIVES.

PREPARED ESPECIALLY AS A  
MANUAL AND GUIDE  
IN THE LABORATORY OF THE  
U. S. ARTILLERY SCHOOL,

BY  
**WILLOUGHBY WALKE,**  
1st Lieutenant, 5th Artillery, Instructor.

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## PREFACE.

The following course of lectures is intended to serve as a manual and guide in the practical laboratory work in the Course of Explosives at the U. S. Artillery School.

The aim has been to present the subject systematically and logically, due consideration being given to the sequence in which the various classes of explosives are arranged, so that a certain degree of familiarity may be acquired in manipulating the less sensitive and dangerous mixtures before undertaking experiments with the high explosives.

Particular attention has been given to the *service tests* of the various explosives, in the description of which all technical terms have been avoided as far as possible.

While the bulk of the matter here presented is the result of compilation, it is believed that a portion, at least, appears in print for the first time.

In submitting these pages, I wish to acknowledge my indebtedness for assistance and encouragement to Professor Munroe, and Lieutenant-Colonel R. T. Frank, 2nd Artillery, Commandant of the Artillery School.

With the permission of Professor C. E. Munroe, Chemist to the U. S. Navy Torpedo Corps, I have borrowed largely from his course of "Lectures on Chemistry and Explosives" delivered at the Torpedo Station, the arrangement of the subject matter being slightly changed to meet the requirements of the Artillery School.

WILLOUGHBY WALKE,

U. S. ARTILLERY SCHOOL,

1st Lieutenant, 5th Artillery.

November, 1891.



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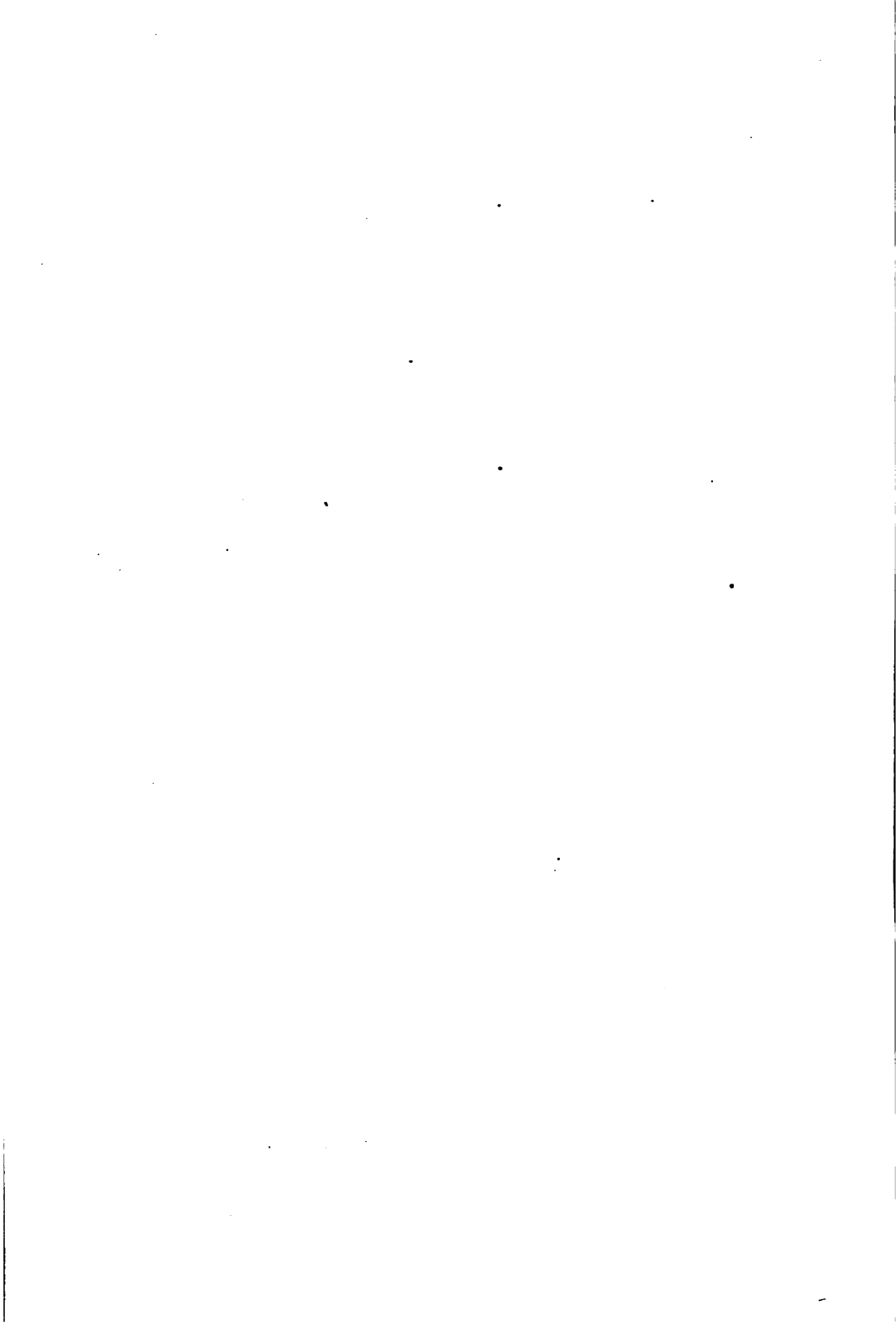
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# LECTURE I.

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## CHEMICAL SYMBOLS, NOMENCLATURE, AND EQUATIONS.

The great importance which has been attached to the subject of explosives within comparatively recent years, and especially the efforts made by all nations to adapt certain high explosives to military purposes, and the investigations looking to the discovery of a suitable propelling agent as a substitute for ordinary gunpowder, all combine to render necessary at least an elementary knowledge of this subject on the part of the scientific officer.

But even the most elementary knowledge of the subject of explosives cannot be obtained without a fair knowledge of their composition, their method of preparation, and the chemical and physical properties of their ingredients, as well as some knowledge of the products of explosion; in other words, knowledge of explosives presupposes a knowledge of chemistry. It is assumed that all who shall read these papers are already well grounded in the principles of chemistry, but some may have had neither the time nor the opportunity for keeping pace with the "*new chemistry*", and it is for the benefit of those members of the class that these preliminary remarks on the chemical philosophy are intended.

The great changes through which chemistry has passed during recent years has affected not only the nomenclature of the science, but the very meaning of many of the terms, so that it will be well to make a brief review of the subject.

The foundation of the modern system of Chemical Nomenclature is to be found in a law first enunciated by an Italian scientist named Amadeo Avogadro, in the year 1811. This law was afterwards reaffirmed by Ampère in 1814, and may be stated as follows: "*Equal volumes of all gases under like conditions of temperature and pressure contain the same number of molecules.*"

The great importance of this law in supplying a truly scientific basis of chemical knowledge, was scarcely appreciated for many years. Indeed, it was nearly half a century after, that it began to make itself felt in attempts to reconcile the very simple system, then in vogue, with the observed facts conforming so clearly with this law. From 1865 to 1870, the "New Chemistry" began to be generally taught in the schools and colleges of America.

The new system is coherent and satisfactory, as, it is believed, will be seen from a brief statement of the leading principles of the modern science.

Nearly all substances are of a compound nature, and may be resolved by various means into simple forms of matter differing widely from the original substances in appearance and properties. This division may be carried to a certain point beyond which no known means will suffice to effect further separation. The substances are then said to have been resolved into their elements. It is not to be understood that, by the term "element", we mean that further decomposition *cannot* be effected, but simply that it *has not* been effected.

Of these substances which have not yet been resolved into simpler forms of matter, 71 are now recognized, and they are called elementary bodies.

METALS.	Sym- bol.	Atomic Weight.	METALS, cont.	Sym- bol.	Atomic Weight.
<i>Aluminium,</i>	Al.	27.	Samarium,	Sm.	150.0
Antimony,	Sb.	120.	Scandium,	Sc.	44.0
Barium,	Ba.	136.8	<i>Silver,</i>	Ag.	108.0
Bismuth,	Bi.	207.5	<i>Sodium,</i>	Na.	23.0
Cadmium,	Cd.	111.8	Strontium,	Sr.	87.4
Caesium,	Cs.	132.6	Tantalum,	Ta.	182.0
<i>Calcium,</i>	Ca.	40.0	Terbium,	Tr.	148.8
Cerium,	Ce.	140.4	Thallium,	Tl.	203.7
Chromium,	Cr.	52.0	Thorium,	Th.	233.4
Cobalt,	Co.	58.9	Thulium,	Tu.	170.4
Columbium,	Cb.	93.8	<i>Tin,</i>	Sn.	117.7
<i>Copper,</i>	Cu.	63.2	Titanium,	Ti.	49.8
Decipium,	Dp.	159.0	Tungsten,	W.	183.6
Didymium,	Di.	145.4	Uranium,	U.	239.8
Erbium,	E.	166.0	Vanadium,	V.	51.3
Gallium,	Ga.	70.0	Ytterbium,	Yb.	172.8
Glucinum,	Gl.	9.0	Yttrium,	Y.	89.8
Gold,	Au.	196.2	<i>Zinc,</i>	Zn.	65.0
Holmium,	Ho.	162.0	Zirconium,	Zr.	89.4
Indium,	In.	113.4			
Iridium,	Ir.	192.7	<b>NON-METALS.</b>		
<i>Iron,</i>	Fe.	56.0	Arsenic,	As.	75.0
Lanthanum,	La.	138.5	Boron,	B.	10.9
<i>Lead,</i>	Pb.	206.5	<i>Bromine,</i>	Br.	79.8
Lithium,	Li.	7.0	<i>Carbon,</i>	C.	12.0
Magnesium,	Mg.	24.0	<i>Chlorine,</i>	Cl.	35.4
<i>Manganese,</i>	Mn.	54.0	<i>Fluorine,</i>	F.	19.0
<i>Mercury,</i>	Hg.	199.7	<i>Hydrogen,</i>	H.	1.0
Molybdenum,	Mo.	95.5	<i>Iodine,</i>	I.	126.6
Nickel,	Ni.	58.0	<i>Nitrogen,</i>	N.	14.0
Osmium,	Os.	198.5	<i>Oxygen,</i>	O.	16.0
Palladium,	Pd.	105.7	<i>Phosphorus,</i>	P.	31.0
<i>Platinum,</i>	Pt.	194.4	Selenium,	Se.	78.8
<i>Potassium,</i>	K.	39.0	<i>Silicon,</i>	Si.	28.2
Rhodium,	Rh.	104.0	<i>Sulphur,</i>	S.	32.0
Rubidium,	Rb.	85.3	Tellurium,	Te.	128.0
Ruthenium,	Ru.	104.2			

The elementary bodies enumerated above combine with each other to form compounds, in which state of combination they usually exist as various forms of matter, and it is the peculiar manner in which these combinations take place that distinguishes true chemical compounds from mere mechanical mixtures.

**The Law of Fixed or Definite Proportions, and the Law of Multiples.**—The first general law governing chemical action was discovered by Wenzel and Richter, in 1777, and it was quickly supplemented by a second law of equal importance.

The first of these, now known as the LAW OF FIXED OR DEFINITE PROPORTIONS, is as follows:

“In every chemical compound, the proportions by weight of the constituent elements are fixed and definite.” (e. g.  $\text{NaCl-PbO-}$ )

The second, or the LAW OF MULTIPLES, states that “When two elements, A and B, are capable of uniting in several different proportions, forming a series of different compounds, the several quantities by weight of B which unite with a fixed quantity of A, bear to each other very simple relations.” (e. g.  $\text{SO}_2\text{-SO}_3\text{-Cr O-Cr O}_2\text{-Cr O}_3\text{-Cr}_2\text{O}_3\text{-}$ )

Seeking for an explanation of these laws, the Atomic Theory, itself as old as philosophy, was first applied by Dalton in 1807.

Dalton revised the hypothesis of atoms to explain the fact that, in chemical combination, elements unite in fixed proportions, and in certain cases in multiple proportions.

In his investigation of the action of air upon binoxide of N in the presence of  $\text{OH}_2$ , he observed that the O contained in 100 vols. of air united with either 36 or 72 vols. of binoxide of N, leaving a residue of pure N gas above the  $\text{OH}_2$ . From this fact he concluded that O combined with a certain quantity of binoxide of N or with double that quantity, but not with any intermediary quantity,  $\text{HNO}_3$  being formed in the first case, and  $\text{HNO}_2$  in the second.

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This led to the consideration of atomic weights, and the idea of representing the composition of bodies by symbols which indicate both the nature and the number of these particles, and the proportion of the elements entering into the combination.

**The Atomic Theory.**—"All matter is composed of minute, indivisible particles, called atoms, each having a constant and definite weight; and when chemical union is observed to take place between two elementary substances, it takes place by the union of these atoms, each to each." The result of such union is called a molecule. Molecules themselves may further unite, making molecules of higher order.

The definition of a molecule may be given thus: It is the smallest portion of a substance which possesses all the properties and only the properties of that substance.

If the subdivision of a compound body of the first order be carried beyond its molecules, the substance is resolved into its constituent atoms, and its characteristic properties disappear. If the body thus subdivided be of the second order, it will be resolved first into its constituent molecules, these molecules still preserving their own peculiar identity; the original substance, however, is no longer recognizable. In this case the subdivision may be carried further, and these molecules separated into their component elementary atoms, but beyond this point, all attempts at further division have failed.

**Chemical Symbols, Notation and Nomenclature.**—The atomic theory is expressed in the language of chemistry, and therefore before entering into a discussion of the theory itself, it will be well to consider the symbols and notation used in modern chemistry, as well as the new chemical nomenclature.

**Elements.**—The atoms of many of the elements are denoted by the first letter of the name, for example H, O, N and C. When however the names of several elements possess the same initial letter, they are distinguished from each other by adding to the initial letter a second characteristic letter from the name, for example, Ca, Cl, Co and Cr. Inspection of the foregoing table will show several symbols which are apparently derived in still another manner, for example, Au, Fe, Pb and Ag.; but the method of notation is the same, the symbols being taken from the Latin names of the elements.

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As a rule, the more recently discovered metallic elements are denoted by the termination "ium"; the newer non-metals by the termination "ine"; e. g. Sodium, Potassium, Chlorine, Bromine, etc. Most of the older elements are named after no fixed rule.

When these symbols are used, they signify something more than the elementary substances which they represent; each symbol represents a definite portion, *one atom*, of the elementary substance, and also a definite weight, *the weight of one atom* of that substance, referred to the weight of another elementary substance, *Hydrogen*, as a standard. More than one atom of any substance is indicated by a coefficient, or by placing the multiplier to the right, above or below, generally below.

**Compounds.**—As already stated, these elements combine with each other to form other compound substances.

A compound resulting from the combination of atoms of different elements is represented by placing the atoms in juxtaposition: e. g. NaCl, PbO, etc.

When several molecules of the substance are to be indicated, a numerical coefficient is attached, or the molecule is enclosed in brackets and the numeral placed to the right and below: e. g.  $3\text{OH}_2$ ,  $(\text{OH}_2)_3$ .

Combination of molecules: e. g.  $\text{ZnOSO}_3-3(\text{Zn}, \text{SO}_4)-2\text{ZnSO}_4$ .

Compounds are termed binary, ternary, quarternary, etc., according as they contain two, three or four elements. Simple binary compounds are usually named by changing the termination of the non-metallic (or if both be non-metals, then the termination of the more electro-negative) element to "ide"; e. g. BaO— $\text{ZnCl}_2$ .

1. *Oxides.* Of the compounds formed by the combination of elements, a very numerous and important class calls for special attention, namely, the *oxides*.

As their name indicates, they are formed by the union of oxygen with other elements, and, following the law of multiples, this combination may produce several oxides of the same element according to the degree of oxidation; e. g.  $\text{CrO}-\text{Cr}_2\text{O}_3-\text{CrO}_2$ -. These compounds are distinguished as mono, di, tri, sesqui, etc.

When an element forms but two oxides or similar binary compounds, it is usual to change the termination of that element to "ous" for the lower, and "ic" for the higher compound; e. g. Cuprous-oxide,  $\text{Cu}_2\text{O}$ , Ferrous-chloride,  $\text{FeCl}_2$ , Cupric-oxide,  $\text{CuO}$ , Ferric-chloride,  $\text{Fe}_2\text{Cl}_6$ , Sulphurous-oxide,  $\text{SO}_2$ , Sulphuric-oxide,  $\text{SO}_3$ . When there are more than two compounds of similar substances, the two middle terms are designated in the manner given, while the compound in which the element of variable valency has a less value than the lower of the middle terms is indicated by the prefix *hypo*, and the one in which it has a higher valency than the upper of the middle terms is indicated by the prefix *hyper* or *per*; e. g.  $\text{Cl}_2\text{O}$ -Hypochlorous oxide,  $\text{Cl}_2\text{O}_3$ -Chlorous oxide,  $\text{Cl}_2\text{O}_5$ -Chloric oxide,  $\text{Cl}_2\text{O}_7$ -Perchloric oxide. For convenience, oxides may be divided into two classes. The first class embraces those oxides which possess the chemical properties of the oxides of K, Na, and Ca, and are called *basic oxides*. The oxides of the second class are those of which the oxides of S, P, C, etc., are types and are called *acid oxides*.

The oxides of the metals generally fall under the first class, while the non-metallic oxides are usually acid.

There is also an intermediate group designated as *neutral oxides* because of their slight disposition to enter into combination; e. g.  $\text{MnO}_2$ . The lines separating these classes are by no means distinctly marked; in fact, the same oxide may exhibit either acid or basic properties according to circumstances.

2. *Acids*. The combination of acid oxides with water forms a class of compounds called *oxy-acids*, which possess in a marked degree the properties termed acid, *i. e.* sour taste, corrosive action, and the power of turning blue-litmus red. Their most characteristic property, however, is that of exchanging the hydrogen which they contain for a metal, forming salts; e. g.  $\text{H}_2\text{SO}_4$ ,  $\text{CuSO}_4$ . Although the origin of acids may be conveniently given in this manner, there is another class of acids, equally important, which cannot be so derived; e. g.  $\text{HCl}$ ,  $\text{HBr}$ , etc. This latter class is sometimes called *hydracids*.

Therefore in defining an acid generally so as to embrace both of these classes, it is best to do so by describing its properties; especially the property of trading its hydrogen for a metal; thus,  $\text{OH}_2$  would be included in the acid class, as it should be, it being an undoubted acid from a chemical point of view.

3. *Salts.* The acid and basic oxides are capable of uniting and forming a class of compounds called "salts"; e. g.  $\text{BaO} + \text{SO}_3 = \text{BaSO}_4$ .

The salts of an "ous" acid are given the termination "ite", and those of an "ic" acid are given the termination "ate"; e. g. Pot. Sulphite,  $\text{K}_2\text{SO}_3$ , Zinc nitrite,  $\text{ZnNO}_2$ ; Pot. Sulphate  $\text{K}_2\text{SO}_4$ , Zinc nitrate  $\text{ZnNO}_3$ .

Salts formed by replacing the hydrogen in hydracids by a metal, are named according to the rule for binary compounds; e. g.  $2\text{HCl} + \text{Zn} = \text{ZnCl}_2$  (Zinc chloride) +  $2\text{H}$ ,  $2\text{HBr} + \text{K} = \text{KBr}_2 + 2\text{H}$ .

**Chemical Reactions.**—When substances do not exist in their native state; e. g. Au., Pt, Cu., etc., they are obtained by three general methods:

1. By decomposition of a compound;—by heat alone—e. g.  $\text{HgO} = \text{Hg} + \text{O}$ .

2. By direct combination of the constituent elements or compounds; e. g.  $\text{Pb} + \text{O} = \text{PbO}$ .

3. By the transformation of previously existing compounds, by means of an auxiliary element or compound.

a. By simple substitution; e. g.  $2\text{HCl} + \text{Zn} = \text{ZnCl}_2 + \text{H}_2$ .

b. By double decomposition; e. g.  $\text{CuO} + 2\text{HCl} = \text{CuCl}_2 + \text{OH}_2$ .

The substances used in obtaining these new compounds are called "*reagents*", and the reciprocal action of the chemical agents upon each other is called a "*reaction*".

Reactions are generally expressed in the form of equations, the reagents being placed in the first member, the products obtained in the second.

According to the particular process by which the new substances are obtained, reactions are said to be Analytical, Synthetical or Metathetical. All of these classes are represented by the equations already given.

In the reactions above given, the symbols stand, in a more restricted sense, for molecules of the substances indicated, and although these molecules are invisible, we know that the transformation of a substance can take place only by the transformation of each individual molecule of that substance. (This follows necessarily from the definition of a molecule already given.)

It further follows that in every equation expressing a reaction, both members must contain the same number of atoms of each element, and the sum total of the atomic weights in each of the two members should correspond. These equations, however, are the result of *observation*, and not of *deduction*, and an equation is not necessarily true because it fulfils these tests; and it is not possible to predict the result of an experiment unless all the conditions are fully known beforehand, as the question of the force of chemical affinity is subject to many modifying influences.

Possessing this knowledge, however, from the considerations just given, it is possible to write the equation which may be assumed to represent any particular chemical reaction by placing the formulae of the substances taken on the left hand and the formulae of the products on the right hand, and connecting them by the proper signs. To determine the coefficients to be prefixed to each term contained in the equation so as to make it a true one, recourse is had to the algebraic method of Simultaneous Linear Equations.

To apply this method, write the equation as above directed, placing literal coefficients before each term in the equation. Then begin with the first term of the first member of the equation and proceed with each separate symbol throughout the entire equation, and we shall obtain a linear equation for each element, which shows the number of times that the element appears in the reaction. Solving these equations and reducing to the least whole numbers, we obtain numerical coefficients which are to be substituted for the literal ones in the original equation. For example:

If we boil metallic silver with strong sulphuric acid, the products are  $\text{Ag}_2\text{SO}_4$ ,  $\text{H}_2\text{O}$  and  $\text{SO}_2$ .

Write the equation as follows; Ag being the symbol for silver, and  $\text{H}_2\text{SO}_4$  the symbol for sulphuric acid,



$$a = 2x \quad . \quad . \quad . \quad (1)$$

$$2b = 2y \quad . \quad . \quad . \quad (2)$$

$$b = x + z \quad . \quad . \quad . \quad (3)$$

$$4b = 4x + y + 2z \quad . \quad (4)$$

As  $b$  appears in three of the linear equations, assume  $b=1$ ; then from (2),  $y=1$ .

Substituting these values for  $b$  and  $y$  in (3) and (4), we find  $x=\frac{1}{2}$  and  $z=\frac{1}{2}$ , and hence from (1),  $a=1$ .

Hence  $a=1$ , reduced to whole numbers,  $a=2$

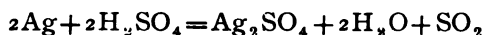
$$b=1, \quad b=2$$

$$x=\frac{1}{2}, \quad x=1$$

$$y=1, \quad y=2$$

$$z=\frac{1}{2}, \quad z=1$$

Substituting these values, we have



which is a true equation.

Before entering into the subject of Chemical Philosophy proper, it is necessary to supplement the outline of chemical nomenclature by defining more fully some of the terms already given, and by introducing and explaining a few others.

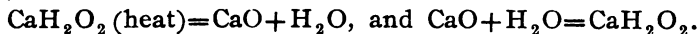
**Radicals.**—In metathetical reactions, the interchange may be of two atoms each for each, one atom of one substance for two or more atoms of another substance, one or more atoms for a group of different atoms, or it may consist of an exchange of two different groups of atoms; e. g.  $\text{AgNO}_3 + \text{NaCl} = \text{AgCl} + \text{NaNO}_3$ ;  $\text{AgNO}_3 + \text{NH}_4\text{Cl} = \text{AgCl} + \text{NH}_4\text{NO}_3$ . Such groups of atoms are supposed to be transferred from one compound to another without loss of integrity. They are called *compound radicals*. Although they are not, for the most part, capable of existing in the separate state, their existence as integral parts of compounds is assumed for convenience in grouping and classifying compounds. They are classed as acid or basic, according to their affinities; e. g.  $\text{K}_2\text{O}$ ,  $\text{As}_2\text{O}_5$ ,  $\text{Na}_2\text{SO}_4$ . The basic radicals are also called electro-positive, and the acid, electro-negative radicals.

The terms electro-positive and electro-negative are in a measure synonymous with metallic and non-metallic. Whenever a compound substance is electrolyzed, the metallic element goes to the negative pole and the non-metallic element to the positive pole; and if each element be compared with all of the other elements, it will be found that they can be arranged in a series in which, beginning at the electro-negative end, each element will be electro-positive to any element preceding it, and electro-negative to any element which follows it.

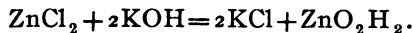
**Bases.**—The term "*base*" in chemistry is a more general term than "basic oxide" (already mentioned) and includes an important class of substances called "hydrates". These contain a metal or basic radical with hydrogen and oxygen; e. g. KHO, NH<sub>4</sub>HO. These hydrates were formerly supposed to contain water, thus  $K_2O + OH_2 = 2KHO$ , but it is now believed that the H and O are present in the form of hydroxyl HO.

Of these bases or hydrates, those of K, Na, Li, Cs, and Rb are characterized by being powerfully caustic, not decomposable by heat, soluble in water, and uniting with fats to make soaps. They are called the *alkalies*.

The hydrates of Ca, Sr, Ba, and Mg are called *alkaline earths*. They are less soluble in water than the alkalies, may be decomposed by heat into a metallic oxide and water, and when the anhydrous oxide is again mixed with water, the hydrate is formed, thus,



The hydrates of many of the other metals are still more readily decomposed by heat, and cannot as a rule be formed direct from the oxides and water. They may be obtained by adding a solution of a soluble salt of the metal to one of the hydrates named above, thus,

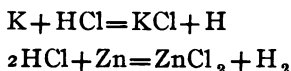


The term "*base*", in its strictly technical meaning, is applicable only to the hydrates, as already indicated, the anhydrous oxide being called a *basic anhydride*. This distinction is comparatively recent, and is by no means carefully observed even by modern chemists.



**Basicity of Acids.**—The origin of acids has already been alluded to, and also the formation of salts, by replacing the hydrogen of acids by metals. When an acid contains but *one* atom of hydrogen in its molecule replaceable by a metal or basic radical, it is said to be *monobasic*; when *two*, *bibasic*; when *three*, *tribasic*; etc.

Monobasic acids can form but one class of salts, the metal replacing the whole of the hydrogen in one or more molecules of the acid. Thus,



In bibasic acids, the replacement may be partial or entire, forming two classes of salts, viz: *primary* or *acid* salts, in which only half the hydrogen in the molecule is replaced, and *secondary* salts in which the whole is replaced; in the latter case, if the hydrogen is replaced by one metal, the salt is called *normal*, and if by two metals *double*. Thus,  $\text{KHSO}_4$ ,  $\text{K}_2\text{SO}_4$ ,  $\text{KNaSO}_4$ .

Tribasic acids may form three classes of salts—primary, secondary, or tertiary, including normal, double and triple, in which the hydrogen is wholly or partially replaced by one or more metals.

## LECTURE II.

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### CHEMICAL PHILOSOPHY.

**Equivalent Weights.**—In what precedes, the idea has already been advanced that chemical transformations can occur only by changes in the molecules of the substances, and these changes consist in the interchange or replacement of atoms for each other.

It has been further seen that these replacements always occur in fixed and definite proportions by weight. The quantities by weight, of the substances that are thus found to be chemically equivalent, are called their *equivalent weights*.

While, strictly speaking, quantities of elements could only be said to be equivalent when they had actually replaced each other in combination, it is not necessary that such replacement should actually occur.

If we obtain the equivalent weights of two elements with reference to a third, we have their equivalents with reference to each other. Thus, 35.5 parts by weight of chlorine are known to unite with one part by weight of hydrogen, 23 parts of sodium, or 108 parts of silver. Hence we infer that 1, 23, and 108 are the equivalent weights of H, Na, and Ag.

In a similar way, the equivalents of all elements may be expressed. If these equivalent weights were fixed and invariable, the determination of the atomic weights of the elements would be reduced to a very simple problem; but they are by no means so easily settled. Thus, carbon forms two oxides, in one of which 12 parts by weight of carbon combine with 16 parts by weight of oxygen, and in the other 6 parts by weight of C combine with 16 parts of O.

Hence we see at once that, not only these equivalent weights are not fixed, but cannot be the weights of the atoms, since the atoms have fixed and invariable weights.

**Atomic Weights.**—The Atomic Theory has already been briefly stated, and the distinction between atoms and molecules given.

The prime necessity of determining clearly and precisely the relative weights of the atoms will be readily appreciated, when we consider that these weights furnish the basis of all strictly chemical computations;—*they are the essential data in all quantitative analysis, as well as in the application of chemistry to the necessities of daily life.*

In order to understand the method of determining the atomic weights, it is necessary to remember that although we cannot isolate and operate upon a single molecule of a body, yet in transforming a body, we but transform its individual molecules, and whatever change the body undergoes is also undergone by each molecule thereof, and whatever relation is found to exist among the constituents of a body, also exists among the constituents of a single molecule.

Several means have been resorted to for the determination of atomic weights:

1. *Analysis*—By simply analyzing carefully a substance, we can find the proportions by weight of the constituent elements.

Thus; the analysis of water gives 1 part by weight of H to 8 parts of O. If we knew, then, the number of atoms of each substance in the molecule of water, the relative weights of the atoms of H and O would be known at once.

But there is another compound of H and O, in which the proportions by weight of H and O are as 1 to 16. Now we might assume, (1)—the composition of water to be OH, in which case the composition of the second compound would be  $\text{OH}_2$ , and the atomic weights would be  $\text{H}=1$  and  $\text{O}=8$ ; or (2)—we may with equal propriety assume the composition of water as  $\text{OH}_2$ , in which case, the second compound would be OH (or more properly  $\text{O}_2\text{H}_2$ ) and the atomic weights would be  $\text{H}=1$  and  $\text{O}=16$ . Therefore the results of analysis alone would not be sufficient to determine the atomic weights; they might be correct or they might be multiples or submultiples of the correct ones, depending upon whether or not the number of atoms which enter the molecule was correctly assumed.

2. *Substitution*.—This method may be used as an auxiliary to the foregoing one to enable us to fix the number of atoms in the molecule. For example, if we act upon water with metallic sodium, half the hydrogen will be expelled and a compound formed, which gives on analysis 1 part of H, 23 of Na, and 16 of O, and by drying this compound, and further heating with Na, the remaining H is expelled and a compound containing 46 parts of Na and 16 of O remains. Here we see that the H has been expelled by halves, and are thus certain that there must have been at least two atoms of H in the molecules. If we know the number of atoms of O in the molecule, we would have the required relative weights of the atoms of H and O; but we do not know this and the problem is still unsolved.

3. *Decomposition*.—By decomposing certain bodies and forming others, it is sometimes possible to determine the number of atoms in the second compound, when the number in the first is known. These are the only purely chemical methods for determining the atomic weights and it has been seen that they are not conclusive. By combining these, however, and carefully comparing the results of the analysis of many different chemical compounds, the chances of error become very small. These purely chemical methods for the determination of atomic weights have been supplemented by means dependent upon physical considerations, and especially on the Law of Avogadro.

**The Law of Avogadro.**—In the light of modern knowledge, this important Law may be said to be derived from the Law of Mariotte and the Law of Charles. According to the first named law, *the volume of a gas varies inversely as the pressure exerted on it.*

According to the second, *the volume of a gas varies directly as the absolute temperature.*

If we admit that the molecular theory be true, that is, that a gas is but a collection of moving molecules,—then the gas is subject to the laws of aeriform matter, and the theory may be said to be, in one sense, capable of physical proof.

But there is much chemical evidence of the truth of this theory. It consists in a comparison of the known atomic weights of certain substances and their specific gravities in the gaseous state.

Professor Cooke, in his lectures, emphasizes the great importance of this Law as follows:

"It would be impossible \* \* to make the force of this evidence apparent, because, so far as Chemistry is concerned, the law of Avogadro is a generalization from a large mass of facts, and the proof of its validity is to be found solely in the circumstance that it not only explains the known facts of chemistry, but that it is constantly leading to new discoveries.

"This law, as I have intimated, bears the same relation to modern Chemistry that the law of gravitation does to modern Astronomy. Modern Astronomy itself is the proof of the law of gravitation; modern optics is the proof of the undulatory theory of light; and so the whole of modern chemistry, and nothing less, is the proof of the law of Avogadro. I do not say, that this great law of modern Chemistry stands as yet on as firm a basis as the law of gravitation, but I do say that it is based on as strong foundation as the undulatory theory of light, and is more fully established to-day, than was the law of gravitation more than a century after it was announced by Newton."

Assuming, then, the law of Avogadro as an established principle, an important corollary at once follows:

"The molecular weights of substances are directly proportional to their specific gravities when in the gaseous state, or the actual weights of the molecules are to each other as the actual weights of equal volumes of those substances in the gaseous state, the conditions of temperature and pressure being the same."

If, then, we assume the weight of the molecule of any gas—as for example H—as a standard, we may obtain the molecular weight of any other gas by simply finding its specific gravity referred to the standard gas.

For example, a given volume of O is found to weigh 16 times as much as the same volume of H, and since the volumes contain the same number of molecules, it follows that the molecule of O is 16 times as heavy as the molecule of H; similarly the specific gravity of hydrochloric acid,—a gas—is found to be 18.25, and the molecule of HCl weighs 18.25 times as much as the molecule of H.

It is evident that if we adopt the weight of the molecule of H as the standard for molecular weights, the molecular weights would be represented by the same numbers as the specific gravities; but if we take the weights of the *half molecule* of H as the standard, the molecular weights of the various gaseous substances would be represented by numbers which are twice their specific gravities.

For reasons which will be shown later, it is found better to adopt the latter standard.

This little weight has been called by Prof. Cooke a "microcrith." Remembering then, that H is our standard for specific gravities, it is evident that we may obtain the molecular weights of the various gases in terms of our unit—the microcrith—by simply doubling the numbers which denote the specific gravities; e. g. the specific gravity of HCl being 18.25, its molecular weight is 36.5 mc.; the specific gravity of  $\text{NH}_3$  is 8.5 and its molecular weight is 17 mc.

In the case of water, we have seen that analysis gives us the proportions of the constituent gases by weight as  $\text{H}=1$  and  $\text{O}=8$ ; this ratio holds also, however, for 2:16, 3:24, 4:32, etc., and we cannot tell from the results of analysis, whether the molecular weight of water vapor is 9, 18, 27, or 36.

But if we determine the specific gravity of water vapor referred to H, we find it to be 9, and hence conclude that the molecule of water weighs 18 mc.

This enables us, then, to determine the molecular weight of all volatile substances and enables us in many cases to decide doubtful atomic weights.

For further explanation and illustration, the following three tables have been prepared.

TABLE I.

Symbol of Compound.	Specific Gravity.	Molec. Weight in mc.	Proportion of H.	Microcrits of H.
HCl	18.25	36.5	$\frac{1}{36.5}$	1
HBr	40.50	81.	$\frac{1}{81}$	1
OH <sub>2</sub>	9.	18.	$\frac{2}{18}$	2
SH <sub>2</sub>	17.	34.	$\frac{2}{34}$	2
NH <sub>3</sub>	8.5	17	$\frac{3}{17}$	3
PH <sub>3</sub>	17.	34.	$\frac{3}{34}$	3
CH <sub>4</sub>	8.	16.	$\frac{4}{16}$	4
C <sub>2</sub> H <sub>4</sub>	14.	28.	$\frac{4}{28}$	4

TABLE II.

Symbol of Compound.	Specific Gravity.	Molec. Weight in mc.	Proportion of O.	Microcrits of O.
H <sub>2</sub> O	9.	18.	$\frac{16}{18}$	16
CO	14.	28.	$\frac{16}{28}$	16
CO <sub>2</sub>	22.	44.	$\frac{32}{44}$	32
SO <sub>2</sub>	32.	64.	$\frac{32}{64}$	32
SO <sub>3</sub>	40.	80.	$\frac{48}{80}$	48
O	16.	32.	$\frac{8}{32}$	32

TABLE III.

Symbol of Compound.	Specific Gravity.	Molec. Weight in mc.	Proportion of Cl.	Microcrits of Cl:
HCl	18.25	36.50	$\frac{35.50}{36.50}$	35.50
C <sub>2</sub> H <sub>3</sub> OC1	39.25	78.50	$\frac{76.50}{78.50}$	35.50
COCl <sub>2</sub>	49.50	99.	$\frac{71}{99}$	71.
PCl <sub>3</sub>	68.75	137.50	$\frac{106.50}{137.50}$	106.50
CCl <sub>4</sub>	77.	154.	$\frac{142}{154}$	142.
Cl	35.50	71.	$\frac{71}{71}$	71.

If we examine the preceding tables, we shall see that thus far they are based only on the results of chemical analysis and arithmetical computations.

It is true that our unit for molecular weights is as yet arbitrary, but the reason for adopting this unit now becomes apparent.

Let us consider the first table, in which are formulated the compounds of H.

It will be observed that no weight of less than one microcrith of H enters any of these compounds, and if this table, which is simply representative, were extended to embrace all the known compounds of H, the same fact would be observed in all.

Similarly, in the compounds of Cl, the smallest weight of Cl is 35.5 microcriths. Furthermore when larger proportions are found, they are always exact multiples of the smallest.

These, then, are the smallest separable weights of the respective elements and must be the chemical units or atoms.

The larger proportions are evidently due to the presence of more than one atom of the element in the compound.

This explains the reason for adopting the half-hydrogen molecule as the standard for molecular weights. If we had adopted the weight of the molecule of hydrogen as the standard, it would be necessary to express the smallest weight of H entering certain compounds by  $\frac{1}{2}$ .

This is the smallest weight of matter that has ever been separated, and has been assumed as the standard for atomic weights. Since it is the half molecule of H, the molecule of H must contain two atoms, and it will be observed from the Tables that the same has been proved true for the molecule of O and Cl.

The same may be extended to all other gaseous elements, and the same fact will be found to obtain in all except *four* (P, As, Hg, Cd.)

This important fact may also be established from the Law of Avogadro by another means.



It is known by experiment that one volume of H combines with one volume of Cl to form two volumes of HCl. Now from the Law of Avogadro, the number of volumes of the new gas must be just double the number of molecules in either of the volumes of the original gases. Call the number of molecules of HCl,  $2n$ , the number of molecules of H or Cl would be  $n$ .

But since each molecule of HCl must contain at least one atom of H and one atom of Cl, there must be  $2n$  atoms of each of the constituent gases, and since there are  $2n$  atoms to  $n$  molecules there must be two atoms to each molecule.

It must be remembered in all that precedes that, while we do not and cannot isolate and weigh single atoms or single molecules, the substance itself is but a collection of exactly similar molecules, and no change can take place in the chemical character of the substance, save through a similar change in its constituent molecules.

Once having admitted the truth of the Atomic Theory, we are enabled to assert with positiveness the changes that occur in the molecules of the substance under examination.

These atomic weights are real and actual weights in terms of a known standard. The size and weight of the molecule have also been approximately determined in terms of our common weights and measures, but the methods by which this has been accomplished cannot be described in the limited time allotted to this Course.

**Volume Relations of the Elements and Compounds.**—It has been shown, as a necessary consequence of the law of Avogadro, that the molecules of all gases, whether elementary or compound, occupy twice the space of the hydrogen atom. Since the gas is but a collection of molecules, it follows that the same proportion of the constituents, both as to weight and volume, must exist in any larger volume, as for example, a cubic foot, or a cubic metre, that exists in one molecule, and whatever be the number of the constituents, they must all be condensed in *two volumes* in the compound. For example:

- 1 vol. of O and 2 vols. of H gives 2 vols. of  $\text{OH}_2$ .  
1 vol. of N and 3 vols. of H gives 2 vols. of  $\text{NH}_3$ .  
2 vols. of CO and 2 vols. of Cl gives 2 vols. of  $\text{COCl}_2$ .

But we have seen that the molecules of the elementary gases (with the four exceptions named) occupy twice the space of the H atom, therefore the atomic weights and specific gravities will be represented by the same numbers, viz: the halves of their molecular weights.

Since, then, equal volumes contain atomic proportions by weight and since the elements unite atom to atom, it will be seen that the number of volumes entering any compound of this class will be the same as the number of the atoms which enter.

We can, therefore, by a simple inspection of the formula of a compound tell the number of volumes which go to make it up; e. g.

$\text{OH}_2$  contains 1 vol. of O and 2 vols. of H;

$\text{NH}_3$  contains 1 vol. of N and 3 vols. of H.

The volume of the atom of an elementary gas is sometimes called the combining volume. From the law of Avogadro, the atoms of the elementary gases, with the exceptions given, occupy equal spaces, and since these atoms are the chemical units, it is evident that these combining volumes are equal.

**Physical Relations of the Atomic Weights.**—The great importance of settling definitely and precisely the atomic weights of elementary substances, has already been alluded to and cannot be overestimated. It therefore remains to mention a few more considerations which aid in determining the atomic weights of solids.

1. *Specific Heats.*—If the specific heats of the solid elements be computed for equal weights, no relation will be found to exist between the results obtained; but if, instead of taking equal weights, quantities proportional to the atomic weights be taken, the results come out very nearly the same, so that the specific heats are inversely proportional to the atomic weights. In other words, the product of the specific heats by the atomic weights is very nearly constant, being about 6.4. The importance of this

fact in determining doubtful atomic weights is obvious; for, the specific heat of an element being known, it is only necessary to divide the number 6.4 by the specific heat to obtain the required atomic weight. For example:

We have seen that analysis will give the proportions of the constituents of a compound with a great degree of accuracy and if we can decide as to the number of atoms of the respective elements in the compound, the atomic weights become known; e. g. analysis shows that silver chloride contains 108 parts of silver and 35.5 parts of chlorine—with this fact alone we cannot tell whether there be one or more atoms of silver, but by dividing 6.4 by the specific heat of silver (0.57) we get 112, a number so nearly coinciding with the result of analysis as to show beyond doubt that there is but one atom. As the result of analysis is more reliable than the determination of specific heat, we accept 108 as the weight of the atom of silver—the specific heat merely deciding us as to the number of atoms in the compound.

2. *Isomorphism*.—When chemical compounds crystallize in the same geometrical form, they are said to be isomorphous.

Many isomorphous compounds are found to be capable of replacing each other in the same crystal without altering the form of the crystal. When this is the case, a similarity of chemical composition is observed in the two compounds; that is, their molecules contain the same number of atoms, and these atoms are supposed to be similarly arranged.

This sometimes enables us to fix the number of atoms in a compound, and hence to determine atomic weights. For example:

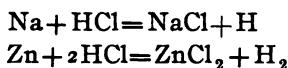
The oxide of aluminium gives on analysis 18.3 parts of Al to 16 of O. If we suppose the compound to be monoxide, the formula would be  $\text{AlO}$ , and the atomic weight of Al, 18.3; if we suppose it to be a dioxide,  $\text{AlO}_2$  and the atomic weight of Al, 36.6; if a sesquioxide, then  $\text{Al} = 27.4$ .

But this oxide is isomorphous with an oxide of iron which is known to be sesquioxide; hence the oxide of Al is inferred to be likewise a sesquioxide, and the atomic weight of Al is fixed as 27.4.

This method is chiefly used as a corroboration of the evidence afforded by other methods.

**Valency or Quantivalence.**—It has been seen that the atomic weights are in some cases identical with the equivalent weights of the elements, and in other cases they are simple multiples of the atomic weights.

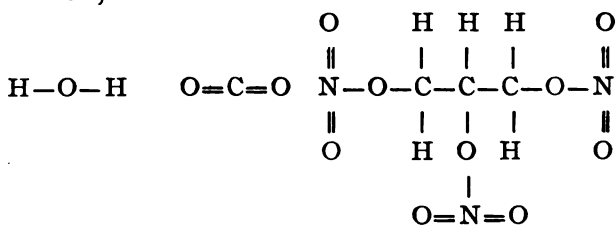
That is, the atoms of certain elements can replace or combine with the atoms of another element only in the proportions of one to one; in other cases, the replacement or combination may occur in the proportion of one to two, one to three, two to three, etc.; e. g.



This difference in combining power has been called *Valency*, *Quantivalence* or *Atomicity*; the first term is the best.

Hydrogen has been selected as the standard for valency, and the elements are classified according to the number of hydrogen atoms which the atoms of the elements can replace or combine with, as monads, dyads, triads, tetrads, etc., or as univalents, bivalents, trivalents, quadrivalents; etc.

The elements of even valency are called *artiads*, the uneven *perissads*. The valency may be denoted by small Roman numerals placed as exponents, or by means of graphic symbols, as represented below;



The valency of an atom as given by its replacing power is the same as given by its combining power; thus Zn can replace two atoms of hydrogen, a monad element, or it may combine with two atoms of chlorine, or bromine, also monads.

The property of valency belongs to radicals as well as to atoms; thus,  $\text{NH}_2$  is a univalent radical.

In the foregoing graphic formulae, it will be noticed that the units of valency of each atom are represented as satisfied by combination with units of valency of other atoms.

Such compounds are called *normal* or *saturated* compounds, and in the molecule of a saturated compound, the sum of the perissad atoms is always an even number.

This is called the Law of Even Numbers, and it is of necessity true for all saturated compounds from the definition of such compounds.

**Variation of Valency.**—In some of the elements (as H, K, Na,) the valency is invariable, but in many others, the valency is not fixed; thus, in CO the C is a dyad, in CO<sub>2</sub> it a tetrad; in FeO the Fe is a dyad, in Fe<sub>2</sub>O<sub>3</sub> it is a triad. S may be bivalent, quadrivalent, or sexvalent; and Cl may be univalent, trivalent, quinquivalent, or septivalent.

The valency in such cases which is usually adopted is that corresponding to its most stable or most common compound.

Valency must not be confounded with affinity. Both are properties inherent in the atoms. Affinity refers to the force which binds atoms or molecules together, a force which is measured by the thermal effects it produces. Valency refers only to the saturating power in combination or replacement, and involves the idea of arrangement of atoms in the molecule.

**Stoichiometry.**—Those chemical computations which may be made from a consideration of the numerical relations of the atomic weights and the volume relations of the elements and compounds are called *stoichiometrical*.

The symbols of the elements represent atoms of those elements, and these atoms have definite weights. The weight of the molecule is the sum of the weights of the constituent atoms. Therefore although the symbols, strictly speaking, represent only one atom each, they may with equal accuracy be taken to represent any other quantities proportional to these atomic weights, so that if the weight of one constituent is known, the weights of the others may be computed by a very simple proportion.

Thus,  $\text{OH}_2$  denotes 18 m. c. of water, made up of 16 m. c. of O and 2 m. c. of H; hence in any other weight of water, the O must constitute  $\frac{8}{9}$  and the H  $\frac{1}{9}$ .

This enables us to calculate the percentage composition of any substance whose formula is given. For example:

The formula of alcohol is  $\text{C}_2\text{H}_6\text{O}$ , its molecular weight 46, and the proportion of its constituents is

$$\left. \begin{array}{l} \text{C} = 24 \\ \text{H} = 6 \\ \text{O} = 16 \end{array} \right\}, \text{ or in 100 parts } \left\{ \begin{array}{l} \text{C} = 52.18 \\ \text{H} = 13.04 \\ \text{O} = 34.78 \end{array} \right.$$

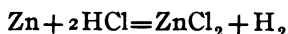
Conversely, from the percentage composition of a compound as given by analysis, we may, by reverse process, compute the numerical relation existing between the atoms of a compound, or its empirical formula.

To obtain from this the molecular formula which gives the exact number of atoms in the compound, other considerations must be introduced, such as vapor density of the compound when in the gaseous state, or the various steps by which one of its constituent elements may be replaced, etc.

Since, as previously stated, the symbols of the elements may be taken to represent any quantities proportional to the atomic weights, we may readily compute the weight of any substance involved in a chemical reaction when the weight of one of the substances is known.

Thus, suppose it be required to find the weight of HCl necessary to dissolve 10 grammes of zinc.

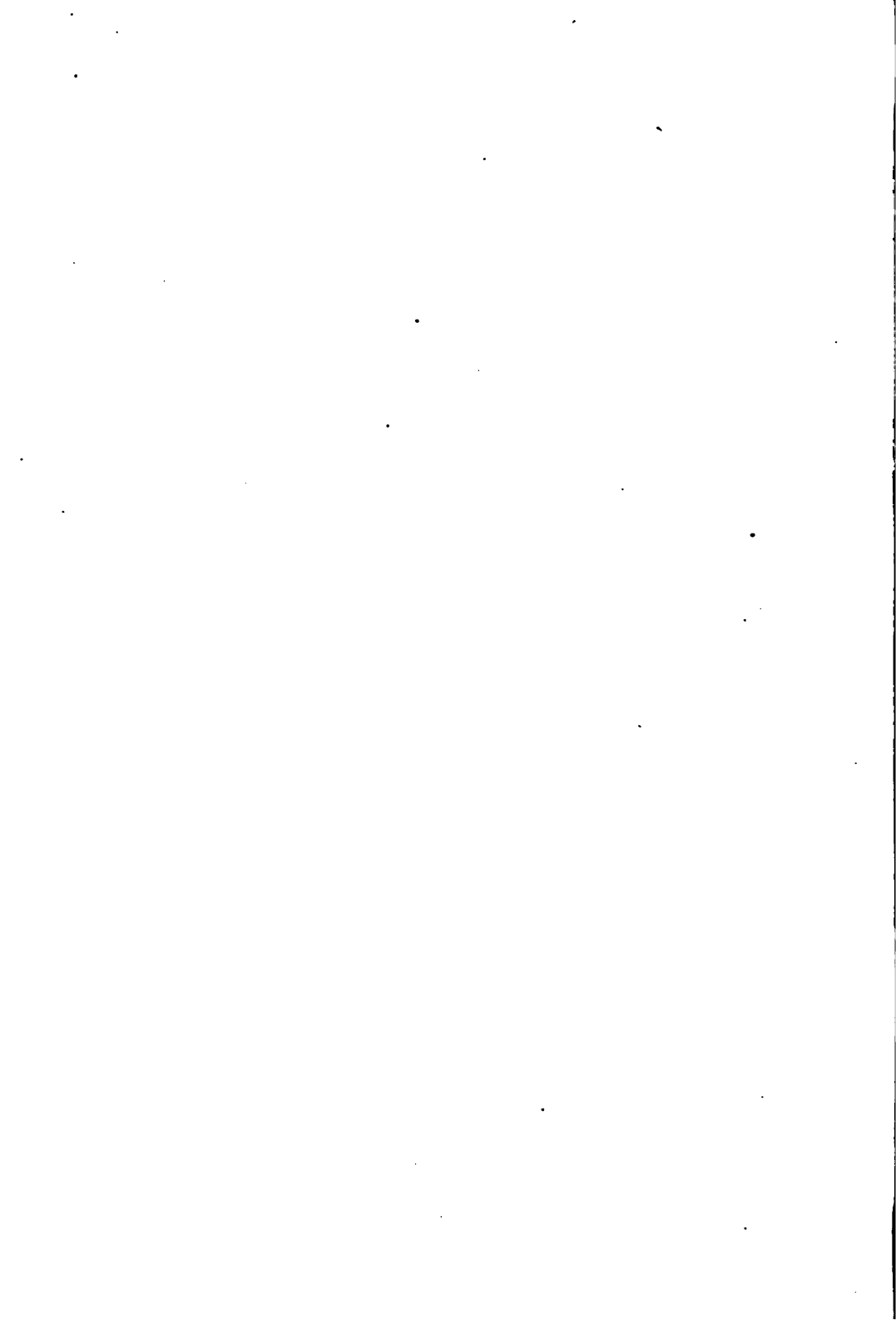
The equation is



The atomic weight of Zn is 65.2 and the molecular weight of HCl is 36.5, hence  $2\text{HCl} = 73.0$ . It is seen therefore that 73 parts by weight of HCl dissolve 65.2 parts of Zn, hence the amount required to dissolve 10 grammes of zinc would be given by the proportion,

$$65.2 : 73.0 :: 10 : x$$

Similarly we could compute the amount of H evolved, or of  $\text{ZnCl}_2$  formed.



## LECTURE III.

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### CHEMISTRY OF SOME OF THE MORE IMPORTANT SUBSTANCES WHICH ENTER INTO THE COMPOSITION OF EXPLOSIVES.

1. **Potassium Nitrate**—Saltpetre or Nitre— $\text{KNO}_3$ , is found in some parts of India, especially in Bengal and Onde, where it sometimes appears as a white incrustation on the surface of the soil, and is often mixed with it to a considerable depth. The nitre is extracted from the earth by treating it with water, and the solution is evaporated, at first by the heat of the sun, and afterwards by artificial heat, when the impure crystals are obtained, which are packed in bags and sent to different countries as *grough* (or impure saltpetre). It contains a quantity of extraneous matter varying from 1 to 10 per cent., and consisting of the chlorides of potassium and sodium, sulphates of potash, soda and lime, vegetable matter from the soil, sand and moisture. The number representing the weight of impurity present is usually termed the refraction of the nitre, in allusion to the old method of estimating it by casting the melted nitre into a cake and examining its fracture, the appearance of which varies according to the amount of foreign matter present.

Saltpetre also occurs as a saline crust in caverns in some parts of the globe; and in the vicinity of Monclova, Mexico, it is found in great purity in veins or mines.

It exists in certain plants, and is formed spontaneously by the decomposition of animal and vegetable substances when mixed with substances containing potash and kept at an even temperature in moist situations. On this principle artificial nitre beds are made, from which large quantities of nitre are obtained, in France, Germany, Sweden and Hungary. The nitrous earth of India yields about one-fifth of its weight of nitre; that of the nitre caves



from one to ten pounds of nitre to the bushel; while the best nitre-beds afford annually about a quarter of a pound of nitre to a bushel of earth.

Most of the saltpetre used in the United States for the manufacture of gunpowder is obtained from India, whence it is imported in a crystallized state called *crude saltpetre*, containing generally from 15 to 18 per cent of foreign salts, earths and water. The method of purifying it for use in the manufacture of gunpowder will be described hereafter.

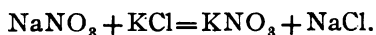
The role played by saltpetre, and the nitrates as a class, in explosives is that of oxidizing agents. Of the nitrates as yet used in the manufacture of powder, the potassium salt has given the best results; it is less hygroscopic than either  $\text{NaNO}_3$ , or  $(\text{NH}_4)\text{NO}_3$ , while, weight for weight, it produces a much more effective explosive than would result from the use of  $\text{Ba}(\text{NO}_3)_2$ .

Potassium nitrate is distinguishable by the long striated or grooved six-sided prismatic form in which it crystallises, and by the deflagration which it produces when thrown on red-hot coals. It fuses at about  $635^\circ\text{F}$ . to a colorless liquid, which solidifies on cooling to a translucent, brittle, crystalline mass. At red heat, it effervesces from the escape of bubbles of oxygen, and is converted into potassium nitrite ( $\text{KNO}_2$ ), which is itself decomposed by a higher temperature, evolving nitrogen and oxygen, and leaving a mixture of potassium oxide ( $\text{K}_2\text{O}$ ) and potassium peroxide ( $\text{K}_2\text{O}_2$ ). In contact with any combustible body, it undergoes decomposition with great rapidity, five-sixths of the oxygen being available for the oxidation of the combustible substance and the nitrogen being evolved in a free state.

**2. Sodium Nitrate.**—Cubical or Chili Saltpetre— $\text{NaNO}_3$ . This salt has been proposed as a substitute for potassium nitrate in the manufacture of gunpowder, but, as already stated, on account of its hygroscopic properties, it has never been adopted, since gunpowder made with it would, under ordinary conditions, soon become useless from moisture absorbed from the atmosphere. In a hot, dry climate, sodium nitrate powders, if made only a short time before being required for use, would be valuable, and cheaper than ordinary gunpowder, and such powders were largely used in the construction of the Suez Canal, and continue to be used for

blasting in mines. Absolutely pure sodium nitrate is said to be not unduly deliquescent, but the material as found in commerce contains other salts which are supposed to induce this property, and are difficult to remove by any reasonably economical process.

The salt is however indirectly largely and increasingly used in the manufacture of gunpowder, for by the simple process of boiling it with potassium chloride, it is converted into  $\text{KNO}_3$  which is retained in the hot solution while sodium chloride is deposited—



As an oxidising agent, sodium nitrate contains more *available* oxygen than the potassium salt, but at very high temperatures, it appears to exercise a less powerful oxidizing action upon combustible bodies.

**Qualitative and Quantitative Tests for Nitre.**—As has been already stated, the principal impurities contained in nitre are moisture, sand and organic matter, potassium and sodium chlorides, potassium, sodium and calcium sulphates, and in that prepared from  $\text{NaNO}_3$ , a little of the latter generally remains. These impurities are estimated as follows:

**Moisture.**—The moisture is determined by heating 5 grm. in a weighed crucible to a temperature not beyond the melting point, and determining the loss of weight. If calcium or magnesium nitrates are present, 1 grm. of dry potassium chromate is added to prevent their decomposition.

**Insoluble Matter.**—The fused mass is treated with water, filtered and the insoluble matter dried and weighed.

**Chlorides.**—The filtrate is concentrated by evaporation to a volume N. Reserve one-third of this solution for the estimation of the chlorides, another for that of the sulphates and a third for that of the calcium salts. Say it measures 150 c. c.

Fifty c. c. are placed in a clean porcelain dish, about 30 milligrammes of pure potassium chromate are added, and the solution is stirred until the salt is dissolved, coloring the solution distinctly yellow. A centinormal solution of silver nitrate is prepared by dissolving 1.7 grm. in 1 litre water, 1 c. c. = 0.000585 Na Cl. This

solution is carefully added from a burette or pipette, graduated to  $\frac{1}{10}$  c. c., the solution being constantly stirred, until the red color just begins to be permanent. The amount of silver nitrate solution required is noted. If either the solution of nitre or the silver solution be acid, it must first be neutralized with caustic potash. Suppose 2.6 c. c. of the centinormal silver solution be required, then  $2.6 \times 3 \times 2 \times .000585 = .009$ , the percentage of Na Cl in the nitre.

*Sulphates.*—The sulphates are estimated by means of a centinormal solution of barium chloride, prepared by dissolving 2.44 grammes of the crystallized salt,  $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$ , in 1 litre water, 1 c. c. = .00142 gramme  $\text{Na}_2\text{SO}_4$  or to .00174 gramme  $\text{K}_2\text{SO}_4$ .

Fifty c. c. of the solution N are placed in a platinum dish, mixed with a few drops of acid, then heated to boiling and the centinormal barium chloride solution added from a burette. The number of c. c. required to precipitate the sulphates is noted. The end of the reaction is determined as explained in the analysis of gunpowder for sulphur.\* Say 6.5 c. c. are required, then  $6.5 \times 3 \times 2 \times .00174 = 0.07$  per cent of  $\text{K}_2\text{SO}_4$  in the nitre.

*Calcium Salts.*—The calcium salts are estimated by means of a centinormal solution of ammonium oxalate, prepared by dissolving 160 grammes of the crystallized salt,  $\text{C}_2(\text{NH}_4)_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ , in 1 litre of water, 1 c. c. = .00164 gramme calcium nitrate. The number of c. c. required to precipitate the calcium salts is noted. The end of the reaction is determined as in the estimation of the sulphates. Say 10 c. c. are required, then  $10 \times 3 \times 2 \times .00164 = .098$  per cent of calcium nitrate in the nitre.

*Valuation of Nitre.*—To determine the amount of pure potassium nitrate in a sample of the crude salt, the following method of Abel and Bloxam, of the Woolwich Arsenal, is recommended as the best method now known.

1.5 gramme of the sample is well mixed in a platinum crucible with 2 grammes finely powdered resin, or better with 0.4 gramme of Brodie's finely-divided graphite, and 5.3 grammes pure dry common salt. The heat of a wire-gauge flame is applied until no more vapor is given off; the crucible is allowed to cool down a little,

\*See Lecture VII.

and 1.7 gramme potassium chlorate are added; gentle heat is applied until most of the chlorate is decomposed, then it is heated to bright redness for three minutes. The mass should be liquid and free from floating charcoal. When cool it is removed to a funnel and the crucible washed with boiling water. The mass is then dissolved in hot water, and the solution, colored with litmus, is neutralized by means of a normal solution of sulphuric acid added from a burette.

Brodie's carbon is prepared by mixing coarsely-powdered graphite with  $\frac{1}{4}$  its weight of potassium chlorate, the mixture is added to a quantity of strong sulphuric acid equal to twice the weight of the graphite and heated in a water bath until yellow vapors cease to be evolved. The mass is allowed to cool, is washed, dried and ignited. It swells up and leaves finely divided graphite.

The normal solution of sulphuric acid is prepared by mixing about 300 c. c. of pure sulphuric acid of specific gravity 1.84, or thereabouts, with three or four times its volume of distilled water, allowing to cool and then diluting to 1 litre. 53 grms. of pure dry sodium carbonate,  $\text{Na}_2\text{CO}_3$ , are then dissolved and the solution diluted to 1 litre. 10 c. c. of this solution are placed in a small beaker with a few drops of litmus solution, and the sulphuric acid is added from a pipette graduated to  $\frac{1}{10}$  c. c. until the point of neutrality is reached. Suppose 8.9 c. c. are required, then 890 c. c. of the acid solution made up to 1 litre will be of the required strength.

Refined saltpetre need only be tested for chlorides, the most injurious of the impurities, because they are generally deliquescent salts, thus rendering the powder liable to absorb moisture. Generally the following is a sufficient test. A normal solution of silver nitrate is prepared, containing 170 grammes to the litre. Ten grammes of the refined saltpetre are dissolved, and 1 c. c. of the standard silver nitrate solution is added. After standing for 24 hours it is filtered, and the liquid divided into two portions. To one silver nitrate is added, to the other solution of sodium chloride. One will produce a precipitate: if it is the silver salt, the nitre contains more than .00016 of its weight of sodium chloride; if it is the sodium chloride it contains less than this amount

and is sufficiently pure for the manufacture of gunpowder. The solution of refined nitre should have no action on red or blue litmus paper.

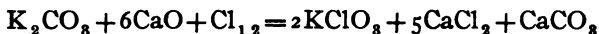
**3. Ammonium and Barium Nitrates.**— $(\text{NH}_4)\text{NO}_3$ — $\text{Ba}(\text{NO}_3)_2$ .

These substances have been experimented with as substitutes for the potassium salt, but with little success.

*Ammonium Nitrate* has recently attracted attention as one of the substances investigated with the object of obtaining a base for the so-called smokeless powders. It is easily prepared by adding ammonium carbonate to slightly diluted nitric acid until saturation is reached. By slow evaporation at a moderate temperature, it crystallizes in six-sided prisms, like those of potassium nitrate. It dissolves in two parts of cold water, producing considerable depression of temperature; it deflagrates like saltpetre on contact with heated combustible matter, and is readily decomposed by heat. Like  $\text{NaNO}_3$ , however, it is hygroscopic, and this property would seem to condemn its use in the manufacture of service powders, which are usually stored for long periods of time in varying climates.

*Barium Nitrate* has been substituted principally to produce a slower burning powder, but the increased weight of the powder resulting from such a substitution is a serious objection. For instance, the chemical equivalent of  $\text{KNO}_3$  being 101, and that of  $\text{Ba}(\text{NO}_3)_2$  130.5, the latter salt increases by one-third the weight of the oxidizing agent necessary to consume a given weight of the combustible. The salt is prepared by dissolving the native carbonate in nitric acid, filtering the solution and evaporating. It crystallizes in transparent colorless octohedrons, which are anhydrous. They require for solution 8 parts of cold and 3 parts of boiling water.

**4. Potassium Chlorate**— $\text{KClO}_3$ .—This salt, so interesting in its application to the manufacture of explosives, is made commercially by mixing potassium carbonate and lime in the proportions of 1 to 6, and saturating the damp mixture with chlorine. On treating the mass with boiling water, a solution is obtained which contains potassium chlorate and calcium chloride—the latter being very soluble remains in the solution, while the  $\text{KClO}_3$  crystallizes out upon cooling. The reaction may be represented as follows:



Potassium chlorate is soluble in about 20 parts of cold and 2 parts of boiling water; the crystals are anhydrous, flat and tabular; in taste it somewhat resembles saltpetre. Like the nitrate,  $\text{KClO}_3$  is employed as an oxydizing agent. When heated it gives off the whole of its oxygen and leaves potassium chloride. It deflagrates violently with combustible matter, explosion resulting from friction or blows, its extreme sensitiveness in this respect precluding its use in the manufacture of gunpowder.

**Qualitative Tests for Chlorates.**—It is often necessary to determine the character of an unknown salt, and should the salt be a chlorate, too much care and circumspection cannot be employed in the methods pursued.

1. To detect the presence of potassium chlorate, place a very small amount of the substance to be examined in a strong test-tube and introduce carefully a few drops of concentrated sulphuric acid, *without heat*. If a chlorate, it will quickly be decomposed, potassium sulphate and perchlorate being formed, while the greenish-yellow fumes of chlorous acid will be evolved.

2. A more delicate test, depending upon the action of chlorine upon indigo (bleaching) may be applied as follows:—Dissolve a little of the salt in water, and color the solution with a few drops of indigo dissolved in sulphuric acid. Add next a little diluted  $\text{H}_2\text{SO}_4$  and then drop by drop a solution of sodium sulphide. Immediately the blue color will disappear due to the action of the liberated chlorine, the sulphurous acid depriving the chloric acid of its oxygen.

3. Put a small quantity of the substance in a strong test-tube and add a little hydrochloric acid. Upon the application of heat, the chlorate, if present, and acid will be decomposed, forming water, chlorine and bichlorate of chlorous acid. The test-tube will become filled with a greenish gas, having the disagreeable odor of chlorine, while the  $\text{HCl}$  also acquires a greenish color.

4. In testing an explosive which is supposed to contain a mixture of chlorates and nitrates, dissolve a small quantity in warm water and filter. The filtrate will contain the nitrates and chlorates. Introduce a little of the filtrate into a test-tube, add to it a few drops of sulphuric acid, and a small strip of zinc. Heat gently and add a few drops of silver nitrate. If a chlorate be present, a white precipitate of silver chloride will be thrown down.

5. **Sulphur**—S. This substance is fully treated under the subject of gunpowder, and very little need be said about it here. Its characteristic yellow color is well known. One of the most remarkable features of sulphur is its inflammability, due to its tendency to combine with oxygen at a moderately elevated temperature. It melts at a heat not much above the boiling point of water ( $239^{\circ}$  F.) and inflames at  $500^{\circ}$  F., burning with a pale blue flame, and emitting the well known suffocating odor of sulphurous acid ( $\text{SO}_2$ ).

**Tests for Crude Sulphur.**—The purity of crude sulphur is determined by heating or burning 20 grammes in a porcelain crucible and weighing the residue; or by dissolving 10 grammes in 50 c. c. carbon bisulphide, washing the residue with ether and weighing.

Refined sulphur contains small proportions of arsenic, antimony, iron and earthy matter. A qualitative test for their presence, together with a direct estimation of the sulphur, is sufficient. Refined sulphur should leave scarcely a trace of incombustible matter, when intended for use in the manufacture of gunpowder. After stirring it with warm water it should not redden litmus paper.

Ten grammes of the sulphur are burnt in a porcelain crucible; the residue contains the iron and earthy matters. The iron is detected by treating the residue with hydrochloric acid and adding potassium ferrocyanide, if iron is present a blue color is produced. Arsenic and antimony are detected by means of the Marsh apparatus. The sulphur is estimated by treating 1 gramme as in the analysis of gunpowder for sulphur.

**6. Charcoal.**—Like sulphur this substance is quite fully described under the subject of gunpowder, of which it is a most important ingredient. As an ingredient of gunpowder, however, it is commonly considered as carbon, pure and simple. This idea is very far from correct. Charcoal is described as the residue of the destructive distillation of wood, in which process the hydrogen and oxygen of the wood are for the most part expelled in the forms of wood naphtha ( $\text{CH}_4\text{O}$ ), pyroligneous acid ( $\text{C}_2\text{H}_4\text{O}_2$ ), carbonic acid, carbonic oxide, water, etc., leaving a residue containing a much larger proportion of carbon than the original wood, and therefore capable of producing a much higher temperature by its combustion with the saltpetre. The higher the temperature to which the charcoal is exposed in its preparation, the larger the proportion of hydrogen and oxygen expelled, and the more nearly does the charcoal approach in composition to pure carbon; but it is not found advantageous in practice to employ so high a temperature, since it yields a dense charcoal of difficult combustibility, and therefore less fitted for the manufacture of powder. The average composition of wood, exclusive of ash, is

Carbon . . .	50 parts
Hydrogen . . .	6 “
Oxygen . . .	44 “
	<hr/>
	100 “

The composition of charcoal prepared at different temperatures is given as follows:

Temperature of charring	Carbon	Hydrogen	Oxygen	Ash
270°C.	71.00	4.60	23.00	1.40
363°	80.10	3.71	14.55	1.64
476°	85.80	3.13	9.47	1.60
519°	86.20	3.11	9.11	1.58



The proportion of carbon, upon which the heating value of the charcoal depends, increases with the final temperature of carbonisation; but it is found that the rapidity with which the temperature is raised has also a great effect in increasing the proportion of carbon, as shown below.

Final Temperature	Time of Heating	Percentage of C.
410°C.	5 hours	81.65
414°	2¾ " "	83.14
490°	3¼ " "	84.19
490°	2¾ " "	86.34
555°	3¾ " "	83.32
558°	3 " "	86.52

The brown charcoal (charcoal roux) is prepared between 260° and 320°.

In addition to the woods mentioned under the article referred to as best suited for making charcoal (alder, willow, etc.,) other materials are now used, notably straw, peat, etc.

**Tests for Charcoal.**—In the laboratory it is only necessary to determine whether the charcoal has been properly charred. For this purpose a determination of its moisture, volatile constituents and ash will be necessary.

**Moisture.**—Ten grammes of pulverized charcoal are heated in a porcelain crucible at 150° C., in a drying oven, for 24 hours. The temperature should be raised gradually. It is allowed to cool in a dessicator and weighed.

**Volatile Matter.**—The crucible containing the dried charcoal is covered, placed in a clay crucible and surrounded with charcoal; the temperature is raised gradually; it is heated at a red heat for half an hour, allowed to cool, and weighed.

**Ash.**—Ten grammes of the charcoal in fragments are burned in a crucible, and the residue is weighed.

**7. Nitric Acid— $\text{HNO}_3$ .** Nitric acid is prepared on a small scale by distilling potassium nitrate with an equal weight of concentrated sulphuric acid. When prepared in large quantities, sodium nitrate, which is cheaper and furnishes a larger proportion of nitric acid, is substituted for the potassium salt.

Thus obtained, nitric acid has a specific gravity of from 1.50 to 1.52; it has a golden-yellow color, due to nitrogen trioxide or tetroxide, which is held in solution. It is extremely corrosive, staining the skin deep yellow and causing total disorganisation. The facility with which nitric acid parts with a portion of its oxygen renders it very valuable as an oxidizing agent, and it is to this property that it owes its importance in its relations to explosives. Comparatively few substances which are capable of forming compounds with oxygen can escape oxidation when treated with  $\text{HNO}_3$ . Its action upon organic substances is most marked, and in many cases, the resulting products exhibit a most interesting relation to original substances. This feature will be noticed later on.

#### **Qualitative Tests for Nitric Acid.**

1. The acid should be clear, and the color should not be a deeper yellow than that of a solution of pure picric acid in water.

2. Determine its real specific gravity by weighing in a carefully calibrated Sp. Gr. bottle at  $15^\circ \text{C}$ ., and comparing the weight obtained with the weight of the same volume of pure distilled water at the same temperature. It should not be less than 1.50 at  $15^\circ \text{C}$ .

3. *For the presence of metals.*—Evaporate about 10 drops on a small piece of platinum foil. There should be no residue.

4. *For the presence of Chlorine and Chlorides.*—Dilute 2 c. c. with a normal solution of  $\text{AgNO}_3$ . No turbidity should be produced.

5. *For the presence of Sulphuric Acid.*—Dilute as in 4, acidulate with  $\text{HCl}$ , and treat with a normal solution of  $\text{Ba}(\text{NO}_3)_2$ . No turbidity should be produced.

6. To determine the percentage of oxides of nitrogen, titrate with a standard solution of potassium permanganate.

**8. Sulphuric Acid.**— $\text{H}_2\text{SO}_4$ . Sulphuric acid is prepared as follows: a mixture of sulphurous acid gas, air, steam and a little vapor of nitric acid, is introduced into a leaden chamber containing a layer of water. The nitric acid is reduced by the sulphurous acid gas to the state of nitrogen monoxide ( $\text{NO}$ ), which takes up oxygen from the air (forming  $\text{NO}_2$ ) and gives it to the sulphurous acid gas, which it converts into sulphuric acid. This is absorbed by the water, forming diluted  $\text{H}_2\text{SO}_4$ , which is concentrated by evaporation first in leaden pans and afterwards in glass retorts and platinum stills. The properties of this acid are very characteristic. Its great weight (Sp. Gr. 1.842), freedom from odor, and oily appearance, distinguish it from any other liquid. When absolutely pure, it is perfectly colorless, but the ordinary acid has a peculiar grey color, due to traces of organic matter. It is powerfully corrosive, and when poured upon a piece of wood, the latter is at once blackened. It possesses very great affinity for water, as shown by the sudden and great elevation of temperature produced on mixing  $\text{H}_2\text{SO}_4$  and water. This latter property is utilized in the laboratory in drying substances without the aid of heat; it is also turned to account in concentrating nitric acid, or in absorbing the water produced during a reaction in which nitric acid plays a part, thereby keeping the latter acid up to its full strength.

#### Qualitative Tests for Sulphuric Acid.

1. The acid should be clear and colorless.
2. Determine its specific gravity as in the preceding test for  $\text{HNO}_3$ . It should not be less than 1.845 at  $15^\circ\text{C}$ .
3. *For the presence of metals.*—Evaporate 10 drops to dryness on a piece of platinum foil. There should be no residue.
4. *For the presence of Lead.*—Dilute 2 c. c. with 5 volumes of distilled water. No turbidity should result.
5. *For the presence of Chlorine and Chlorides.*—Dilute 2 c. c. with 10 volumes of water, acidulate with a drop of  $\text{HNO}_3$ , and treat with a normal solution of  $\text{AgNO}_3$ . No turbidity should result.

6. *For the presence of Nitric Acid.*—Dissolve 1 part of carbolic acid in 4 parts of the  $\text{H}_2\text{SO}_4$ , and add 2 parts of distilled water. There should be no reddish brown color produced in the mixture which turns yellow upon the addition of  $\text{NH}_3$ .

7. *For the presence of Hydrogen Arsenide.*—Dilute 1 c. c. of the acid with 10 c. c. of distilled water, and add 30 drops of  $\text{CuSO}_4$  (solution). Place 5 c. c. of the mixture in a test tube and drop in a piece of pure zinc. Close the tube with a perforated cork in which is placed a piece of filter paper saturated with  $\text{AgNO}_3$  (solution). The paper should not become discolored.

9. **Glycerine**— $\text{C}_3\text{H}_5(\text{OH})_3$ . Glycerine is now largely prepared by the decomposition of fatty substances by means of superheated steam. Thus prepared, it is obtained in great purity. It is a nearly colorless and very viscid liquid of specific gravity 1.25. When quite pure and anhydrous, it crystallizes on exposure to a very low temperature, especially if agitated, as in railroad transport. The crystals are monoclinic, perfectly colorless, and melt at  $60^\circ \text{F}$ . It has an intensely sweet taste, and mixes with water in all proportions: its solution does not undergo alcoholic fermentation, but when mixed with yeast, and kept in a warm place, it is gradually converted into propionic acid. Glycerine is neutral to vegetable colors: heated, it volatilizes in part, darkens and decomposes, giving off among other products, a substance called *acrolein* ( $\text{C}_3\text{H}_4\text{O}$ ), having an intensely pungent odor. According to its chemical constitution, glycerine is an alcohol in which three atoms of hydrogen can be replaced by three acid radicals; and when this takes place, compounds are produced which can be designated as compound ethers, and those fats which contain glycerine such compound ethers, or glycerides.

#### Qualitative Tests for Glycerine.

1. *For the presence of free acids.*—Dilute 2 c. c. with an equal volume of distilled water and shake for a few minutes. Test with litmus paper. Reaction should be neutral.

2. *For the presence of carbonaceous matter.*—Put 4 or 5 drops in a watch crystal and heat gently. It should burn with a pale blue flame, evolving a sweetish to pungent odor, and leave a mere trace of carbonaceous residue.

3. For the percentage of carbonaceous matter, weigh 5 grm. in a porcelain crucible, and heat gently until it inflames. Remove the source of heat until the glycerine is consumed, and ignite the residue thoroughly (to constant weight), and weigh the remaining ash. Distilled glycerine should not yield more than 0.1 per cent of ash.

4. *For the presence of the higher fatty acids.*—Dilute as in 1, and treat with a current of  $N_2O_4$ . It should remain clear and give no flocculent precipitate.

5. *For the presence of Butyric Acid.*—Mix 2 c. c. with 5 or 6 drops of dilute  $H_2SO_4$ . There should be no odor of sweat when the mixture is rubbed between the hands.

6. *For the presence of Formic and Oxalic Acids.*—Mix 2 c. c. with an equal volume of conc.  $H_2SO_4$ . There should be no development of gas, and the mixture should not turn dark when heated.

7. *For the presence of Acrolein.*—Dilute as in 1 and treat with a normal solution of  $AgNO_3$ . It should give no white precipitate (which blackens on standing or boiling) within 24 hours.

8. *For the presence of Formic Acid.*—Dilute as in 1 and treat with  $(NH_4)Ag(NO_3)_2$  (obtained by precipitating Ag from a normal solution of  $AgNO_3$  by adding  $NH_3$  and redissolving the precipitate) at ordinary temperature and in the dark. It should give no black precipitate within one-half hour.

9. *For the presence of Glucose.*—Dilute as in 1, mix with an equal volume of KHO, and heat on water bath. It should not become brown, and, upon the addition of a few drops of  $CaSO_4$  (solution), it should give no precipitate.

10. *For the presence of Cane-sugar.*—Mix with 5 volumes of  $H_2O$  and one-half volume of conc. HCl, and heat to  $70^\circ$  or  $80^\circ$  C for 10 minutes. When heated with Fehling's solution for 5 minutes, it should not sensibly reduce it.

11. *For the presence of organic Ammonias.*—Mix 3 c. c. with an equal volume of KHO in a test-tube, and introduce into the tube above the mixture a glass rod dipped in HCl. No fumes should be given off.

12. *For the presence of Gums and Analogous substances.*—Mix 3 c. c. with an equal volume of a mixture of 2 parts of ether and 1 part of alcohol. The mixture should remain perfectly clear and uniform.

13. *For the presence of Copper, Lead, etc.*—Dilute as in 1, acidulate with HCl, and treat with  $\text{SH}_2$ . It should not become discolored, nor yield a precipitate.

14. *For the presence of Iron, Zinc, etc.*—Make alkaline by the addition of  $\text{NH}_3$  and treat with ammonium chloride and sulphydrous. It should remain clear and colorless.

15. *For the presence of HCl and chlorides.*—Dilute as in 1, acidulate with  $\text{HNO}_3$ , and treat with  $\text{AgNO}_3$  (solution). It should give no precipitate.

16. *For the presence of  $\text{H}_2\text{SO}_4$  and sulphates.*—Dilute as in 1, acidulate with HCl, and treat with  $\text{BaCl}_2$  (solution). It should give no precipitate.

17. *For the presence of Albuminous and coloring matters.*—Dilute with 2 volumes of  $\text{H}_2\text{O}$ , neutralize carefully with acetic acid, expel the  $\text{CO}_2$  by heat, and allow to cool. When cool treat with basic lead acetate. It should give no precipitate.

18. *For the presence of calcium salts.*—Dilute as in 1 and treat with ammonium oxalate. It should give no precipitate.

19. *For the presence of oxalic acid.*—Dilute as in 1 and treat with  $\text{CaCl}_2$  and sodium acetate. It should give no precipitate.

20. **Cellulose**— $n(\text{C}_6\text{H}_{10}\text{O}_5)$ . This substance, also called *Lignin*, constitutes the fundamental material of the structure of plants: it is employed in the organization of cells and vessels of all kinds, and forms a large proportion of the solid parts of every vegetable. It must not be confounded with *lignous* or *woody tissue*, which is in reality cellulose with other substances superadded, encrusting the walls of the original membranous cells, and imparting stiffness

and inflexibility. Pure cellulose, on the other hand, has the same percentage composition as starch; but woody tissue even when freed as much as possible from coloring matter and resin by repeated boiling with water and alcohol, yields, on analysis, a result indicating an excess of hydrogen above that required to form water with the oxygen, besides traces of nitrogen. Pure cellulose is tasteless, insoluble in water and alcohol, and absolutely innutritious; it is not sensibly affected by boiling water, unless it happens to have been derived from a soft or imperfectly developed portion of the plant, in which case, it is disintegrated and rendered pulpy. It is acted upon slightly by dilute acids and alkalis, but in their more concentrated forms, sulphuric and nitric acids transform cellulose into other substances, differing widely from the original.

**11. Glucoses**— $C_6H_{12}O_6$ . The sugars included in this formula may be regarded as aldehydes of the saturated alcohols,  $C_6H_{14}O_6$ . There are several varieties of glucose,—ordinary glucose, levulose, mannitose, galactose, etc., all of which, with one exception, are decomposed by boiling with aqueous alkalis; they are not carbonized by strong sulphuric acid at ordinary temperatures, and when boiled with a solution of potassio-cupric tartrate, they throw down the copper in the form of red cuprous oxide.

*Ordinary glucose* is abundantly diffused through the vegetable kingdom; it may be extracted from the juice of sweet grapes (whence it is often called *grape sugar*), also from honey, by washing with cold alcohol, which dissolves the fluid syrup: but when required in large quantities, it is always prepared from starch. Glucose is much less sweet than cane sugar, and less soluble in water and alcohol. It may be heated to  $120^\circ$  or even  $130^\circ$  without alteration, but above  $170^\circ$ , glucose blackens and undergoes complete decomposition.

**12. Saccharose**— $C_{12}H_{22}O_{11}$ . This substance, commonly known as *cane-sugar*, is found in the juice of many of the grasses, in the sap of trees, in the root of beets; but it is most easily and in greatest quantity extracted from the sugar cane. The sweet taste of sugar, its ready solubility in water, and like properties are well known.

Strong sulphuric acid decomposes dry sugar when heated, (and a concentrated solution, even at ordinary temperature), with copious evolution of sulphurous oxide, and formation of a large quantity of black, carbonaceous matter. By this reaction cane-sugar may be distinguished from glucose. Cane-sugar is easily oxidized.

This substance, as well as that described immediately above, contains large proportions of carbon and oxygen, and readily lend themselves to the production of explosives.

**13. Benzene, or Benzole— $C_6H_6$ .** The distinction now recognized between *benzene* and *benzole* is that the latter term is usually applied to the lighter portions (of lower boiling point) distilled from coal-naptha, while the former refers to that which is distilled from petroleum.

Pure benzene is a brilliant colorless liquid, exhaling a powerful odor of coal gas; it boils at  $176^\circ F.$ , and is very inflammable, burning with a smoky flame. It mixes readily with alcohol and wood-spirit, but not with water. It belongs to the class of hydrocarbons which has recently attracted attention as a probable source of explosive heretofore but little investigated.

**14. Naphthaline or Naphthalene— $C_{10}H_8$ .** *Naphthaline* is the most prominent constituent of the heavy oil of coal tar, and is easily obtained in a pure state from the portions remaining at the close of distillation, by simply pressing the semi-solid mass to remove any liquid hydrocarbons, and boiling with alcohol, from which the naphthaline crystallizes on cooling in brilliant pearly flakes, which may be still further purified by the process of sublimation.

It possesses a peculiar, penetrating odor, and is a remarkably indifferent substance in its behavior. It is mentioned for the same reason that called attention to benzene, namely, as a substance (hydrocarbon) recently investigated with the view of obtaining a new series of explosives.

**15. Acetic Ether— $C_4H_8O_2$ , Acetone— $C_3H_6O$ , etc.** These substances are powerful solvents and, as such, are of great value in the manufacture of explosives.



*Acetic ether* may be obtained by distilling acetic acid with alcohol and sulphuric acid, and diluting the distilled liquid with water. It is easily detected by its pungent odor. *Acetic acid*, from which the ether is obtained is itself an excellent solvent.

*Acetone* is best prepared by the dry distillation of the acetates, the calcium or the lead salt being the most convenient for the purpose. The crude distillate is saturated with potassium carbonate, and afterwards rectified in a water-bath from calcium chloride. Pure acetone is a colorless limpid liquid, of peculiar odor; it is very inflammable, and burns with a bright flame; it is mixable in all proportions with water, alcohol and ether.

No attempt has been made to enumerate even a small proportion of the substances which may and do enter into the composition of the various explosives, but merely to call attention to a few of the more important of those with which we shall have to deal in the practical laboratory work. Almost any substance can be converted into an explosive, and this fact alone would preclude any enumeration of such materials within the limited time at our disposal.

## LECTURE IV.

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### EXPLOSIVE REACTIONS, DETONATION AND THE CONSTITUTION AND CLASSIFICATION OF EXPLOSIVE BODIES.

**Explosive Reactions.**—All chemical changes, whether of combination or decomposition, are called reactions.

Reactions take place in or between molecules. The same atoms are formed after a reaction as were present before, but differently arranged or united, forming molecules, different from those which entered into the reaction. The reaction, then, is a change in the manner in which the attractions or affinities of the atoms are exerted. The operations of these attractions are governed by the circumstances under which they are exercised. Then, in order to produce any desired results, certain necessary conditions must be fulfilled.

These conditions vary between extreme limits. Thus, in one compound, the attractions which bind together its parts may be so feebly exercised that the slightest change in its surrounding circumstances will bring about its decomposition, while to reverse those of another compound may require that the most powerful agencies should be exerted for a long time.

Again, compounds which are stable at the ordinary temperature may be broken up when moderately heated, or reactions which occur at the ordinary pressure may be entirely altered if the same materials are brought together at a different pressure.

Reactions may go on rapidly or slowly, and be accompanied by evolution of gas, heat, light, electricity, etc. When these accompaniments are of a certain kind, explosive effect results, and we have *explosive* reactions; but such chemical changes are governed by the same laws as all reactions.

**Explosion.**—Considering then the term *Explosion*, which is rather loosely used, as synonymous with explosive reaction, we may define it as a chemical action, causing the sudden or extremely rapid formation of a very great volume of highly expanded gas.

*How produced.*—This chemical action may be brought about, or an explosion caused, in several ways. Generally speaking anything that will cause the ignition of a combustible body, will, when applied to an explosive, cause an explosion.

Some of the more common methods of producing an explosion are as follows:

1. Contact with a heated body either solid, liquid or gaseous.
2. Friction.
3. Percussion.
4. Concussion.
5. Electric spark.
6. Electric current.
7. Thermal radiations.
8. Chemical changes.
9. Physical changes.
10. Chemical and Physical changes.

In the above enumeration, the danger attending the application of a heated body to an explosive, for instance, or the passage of an electric spark through it, would suggest itself to the most ignorant or careless person.

Not so, however, in the cases of friction, percussion and concussion, and it is of the greatest practical importance to determine the sensitiveness of the several explosives thereto. This source of danger in manipulating explosives is so great that it is considered necessary to allude to it at the beginning of our work, so that accidents may be avoided.

*Friction.*—There is no absolute scale by which the sensitiveness of explosives to friction can be measured. It is customary to place a small pinch of the sample in a heavy porcelain, wedgewood or iron mortar and rub it with a pestle, gently at first, and with an increasing pressure. Explosives are classed as sensitive or non-sensitive to friction according to the result obtained. In manipulating an unknown explosive, *the rule is to avoid all friction.*

*Percussion.*—By percussion is meant the blow received by the explosive when it is struck between hard surfaces, or by a body moving with very high velocity.

Explosion in such a case is produced by the sudden conversion of mechanical energy into heat. If the heat of the blow is sufficient to raise the temperature of the explosive to its exploding point, an explosion follows. In order to obtain a practical measure of the sensitiveness to percussion of various explosives, the Percussion Gauge devised by Mr. W. R. Quinan is used.

This apparatus consists of a hammer or plunger of dense wood, with a steel disk let into its lower face, but projecting about one quarter of an inch. This hammer or plunger weighs exactly ten pounds, and slides freely up and down in three guides set in a heavy block of wood. A second steel disk set vertically in the block in all respects similar to that in the hammer and directly under it serves as an anvil. One of the guides is graduated to tenths of a foot, so that the blow of the hammer falling from any given distance is readily estimated in foot-pounds.

To use the gauge, the surfaces of the two disks are carefully cleaned, and 5 mg. of the explosive are placed on the anvil. Beginning at the lowest graduation, the hammer is dropped from increasing heights until a complete explosion is obtained—the disks being cleaned and a new charge of the explosive being used for each blow.

*Concussion.*—By concussion is meant the shock or blow delivered by transmission through air or other media intervening between the explosive and the source of disturbance. The danger arising from this sensitiveness is very great, and is rendered all the more difficult to deal with from the impossibility of an exact determination. This quality can be tested only by finding at what distance one cartridge, when exploded, will cause the explosion of another lying in its vicinity. A great number of experiments have been conducted at the U. S. Artillery School Laboratory with a view of establishing some law connecting these explosions between cartridges containing the same explosive, and those containing different explosives, but as yet without success. This subject will be

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considered later under the head of Sympathetic Explosions. The general rule is to have no loose material lying around while testing the various properties of an explosive.

**Explosive Effect.**—Explosive effect is caused by the blow or impulse given by the rapid production of gas in a confined space.

The explosive character of the change, then, depends—

*First.*—Upon the great change of state produced; that is, the formation of gas very much greater in volume than the substance from which it is derived, and which is still more expanded by the heat evolved.

*Second.*—Upon the shortness of time required for the change to take place.

Both of these causes operate to a greater or less extent in all explosive reactions. When both are fully exerted, the most energetic chemical reaction, or in other words, the most violent explosion, takes place. Also, the differences in explosions and explosive bodies depend upon the different manner and proportions in which they are exerted. Thus, nitro-glycerine is much more powerful and violent than gunpowder, because it generates a larger volume of gas in a shorter time. Again, fulminating mercury is not more powerful than gunpowder, although the decomposition goes on more quickly, since the quantity of gas given off, and the temperature of the reaction, are less.

The kinds and quantity of gas given off in an explosive reaction depend upon the chemical composition of the explosive body and the character of the decomposition.

The heat evolved during the reaction adds to the effect by increasing the tension (expanding the volume) of the gas formed. The heat given off in a reaction is an absolute quantity, the same whether the reaction goes on slowly or rapidly. But the *explosive effect* will evidently greatly depend upon the *rapidity* of the formation and expansion of the gas. Thus, if an explosive undergoes the same chemical change under all circumstances of firing, then the total amount of force developed will always be the same, but the *explosive effect* will be increased as the time of action is lessened.

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**Circumstances of Explosion.**—Explosions are greatly affected by the circumstances attending them. Different substances, of course, give different results, from their different compositions and reactions. But we also find that the same substance will exercise a different explosive effect when fired under certain conditions than under others.

These may affect either the rapidity or the results of the chemical change. By shortening the time of the reaction, the explosion is rendered sharper and more violent. With some explosives the decomposition is different under different circumstances. Thus, gunpowder, when fired under great pressure, as in a gun, gives different products than when fired unconfined.

Circumstances of explosion may be generally considered under—

*First.*—Physical or mechanical condition of the explosive body itself.

*Second.*—External conditions.

*Third.*—Mode of firing.

*First.*—*Physical or mechanical condition of the explosive body.* Many instances may be given indicating the influence of its state upon the explosion of a substance. Thus, nitro-glycerine at temperatures above 40° F. is a liquid, and in the liquid condition may be violently exploded by a fuse or exploder containing fifteen grains of fulminating mercury. Below 40° it freezes and cannot be so fired.

The advantage of dynamite over liquid nitro-glycerine lies altogether in the fact that the former contains the explosive body in another mechanical condition, more convenient and safer to use than the liquid form.

The nitro-glycerine itself is the same chemically in either case.

The same mixture of charcoal, sulphur and saltpetre gives a very different effect if made up into large grains than if made up into small ones.

Gun-cotton presents the most marked example of the effect of mechanical state, since it can be prepared in so many ways. If flame is applied to loose, uncompressed gun-cotton, it will flash off; if the gun-cotton is spun into threads or woven into webs, its rate of combustion may be so much reduced that it can be used in gunnery or for a quick fuse; powerfully compressed and wet, it burns slowly; dry gun-cotton may be exploded by a fulminate exploder; wet guncotton requires an initial explosion of a small amount of the dry, etc.

*Second.—External conditions.* Confinement is necessary to obtain the full effect of all explosives. The most rapid explosion requires a certain time for its accomplishment. As the time required is less, the amount of confinement necessary is less. Then with the sudden or violent explosives, the confinement required may be so small that its consideration may be practically neglected. For instance, large stones or blocks of iron may be broken by the explosion of nitro-glycerine upon their surfaces in the open air. Here the atmosphere itself acts as a confining agent. The explosion of the nitro-glycerine is so sudden that the air is not at once moved.

Again, chloride of nitrogen is one of the most sudden and violent of all explosives. In its preparation it is precipitated from a watery liquid, and therefore is, when used, wet or covered with a very thin film of water.

This thin film of water, not more than  $\frac{1}{1000}$ th of an inch in thickness, is a necessary and sufficient confinement; and, if it is removed, the explosive effect is much diminished. Gunpowder on the other hand, requires strong confinement, since its explosion is comparatively slow. Thus, in firing a large charge of gunpowder under water, unless the case is strong enough to retain the gases until the action has become general, it will be broken, and a large amount of the powder thrown out unburned. This is often the case in firing large grained powder in heavy guns. The projectile leaves the gun before all the powder has burned, and grains or lumps of it are thrown out uninjured.

The confinement needed by the slower explosives may be diminished by igniting the charge at many points, so that less time is required for complete explosion.

*Third.—Mode of firing.* In any explosive reaction, the mode of bringing about the change exercises an important influence. The application of heat, directly or indirectly, is the principal means of causing an explosion. Thus, in gunnery, the flame from the percussion-cap or primer directly ignites the charge; so also a fine platinum wire heated by an electric current will ignite explosive material, which is in contact with it. Friction, percussion, concussion, produce the same effect indirectly, by the conversion of mechanical energy into heat, which is communicated to the body to be exploded.

When one explosive body is used as a means of firing another, it may be considered that the blow delivered by the gas suddenly formed from the firing charge acts percussively upon the mass to be exploded. The particles of this gas are thrown out with great velocity, but meeting with the resistance of the mass around them, they are checked, and their energy is converted into heat. It is found, however, that the action of explosives on one another cannot be perfectly explained in this way.

If the action were simply the conversion of energy into heat, then the most powerful explosive would be the best agent for causing explosion. But this is not the case. Nitro-glycerine is much more powerful than fulminating mercury; but fifteen grains of the latter will explode gun-cotton, while seventy times as much nitro-glycerine will not do it.

Chloride of nitrogen is much more violent than fulminating mercury, but larger quantities of the former than of the latter must be used to cause other explosions.

Again, nitro-glycerine is fired with certainty by a small amount of fulminating mercury, while with a much larger amount of gun-powder the explosion is less certain and feebler.

In these cases, it is evident that the fulminating mercury must have some special advantage, since it produces the desired effect more easily than the others. It may be considered that the fulminating mercury sets up a form of motion or vibration, to which the other bodies are sensitive. Just as a vibrating body



will induce corresponding vibrations in others, so the peculiar rate of motion or wave of impulse, sent out by fulminating mercury, exerts a greater disturbing influence upon the molecules of certain bodies than that derived from other substances.

An explosive molecule is unstable, and very susceptible to external influences. Its atoms are in a nicely balanced state of equilibrium, which is, however, more readily overturned by one kind of blow than another. The explosive molecule takes up the wave of impulse of the fulminate, but the strain is too great, and its own balance is destroyed.

In addition, the explosion proceeds very differently when brought about in this way than when caused by simple inflammation. When a mass of explosive is ignited by a flame, the action extends gradually through it; but if it is exploded by a blow, acting in the manner above described, it is plain that the explosion will be nearly instantaneous throughout, since the impulse will be transmitted through the mass with far greater rapidity than an inflammation proceeding from particle to particle. The explosive reaction will then proceed much more rapidly, and the explosive effect will be much sharper, that is, more violent.

It is found that this difference in explosive effect according to mode of firing is very marked, and it is indicated in the use of the term Detonation.

**Detonation.**—Detonation is the instantaneous explosion of the whole mass of a body. Thus, when gunpowder is fired in the usual manner, true combustion takes place, which goes on, with comparative slowness from the surfaces of the grains towards their interiors. On the other hand, when nitro-glycerine is fired by means of fulminating mercury, the whole mass explodes simultaneously, or nearly so.

Doubtless, a certain time is always necessary; but with the so-called detonating explosives it can be practically neglected, and the explosion called instantaneous.

**Theory of Detonation.**—The rationale of detonation is not yet understood. If the transformation were due merely to the mechanical energy of the particles of gas, liberated from the initia-

tory charge at a tremendous velocity, being converted into heat by impact against the mass of the explosive substance, then it would follow that the most powerful explosive would be the best detonating agent; that is, however, by no means the case, for a few grains of fulminate of mercury in a metal tube will detonate gun-cotton, whereas nitro-glycerine, although possessed of more explosive force, will not do so unless used in large quantities. The fact of its being possible to detonate wet gun-cotton is also a proof that the action cannot be due to heat alone. It would rather seem to be what Professor Bloxam terms "sympathetic" explosion; the experiments of Abel, as well as those of Champion and Pellet in France, appear to indicate a vibratory action of the detonating agent upon the ultimate particles of the substance to be exploded.

An explosive molecule is most unstable, certain very delicately balanced forces preserving the chemical and physical equilibrium of the compound.

If these forces be rapidly overthrown in succession, we have explosion; but when, by a blow of a certain kind, they are instantaneously destroyed, the result is detonation. Just as a glass globe may withstand a strong blow, but be shattered by the vibration of a particular note, so it is considered by some authorities that, in the instance cited, the fulminate of mercury communicates a vibration to which the gun-cotton molecule is sensitive, and which overthrows its equilibrium; it is not sensitive to the vibrations caused by nitro-glycerine, which only tears and scatters it mechanically. Although the action of detonation has been spoken of as instantaneous, and may practically be so considered, yet a certain infinitesimal duration of time is required for the metamorphosis; different substances possess, doubtless different rates of detonation, for we can scarcely conceive of a mechanical mixture, such as gunpowder being so sensitive to the action of the detonating impulse as a definite chemical compound, and the rate even varies slightly, for the same explosive, with its chemical state. It has been shown, by means of Captain A. Noble's chronoscope, that compressed gun-cotton, when dry, is detonated at a velocity of from 17000 to 18000 feet a second; or about 200 miles a minute;

by using a small primer of dry gun-cotton, the same substance in the wet state may be detonated at the increased rate of from 18000 to 21000 feet a second, or about 240 miles a minute.

**Bodies susceptible of Detonation.**—Some explosives seem to always detonate no matter how fired (e. g. chloride of nitrogen, the fulminates, etc.), while others are detonated or not, according to the mode of firing (e. g. gun-cotton, gunpowder, etc.)

Probably all explosives can be detonated if the right methods of doing so are known.

Gun-cotton seems to have a greater range of susceptibility to different modes of firing than any other explosive agent. It can be made to burn slowly without explosion, and the rapidity of its action can be increased up to the detonating point.

Nitro-glycerine always explodes powerfully, but its effect is much lessened when fired with gunpowder.

Gunpowder, as ordinarily used, is, of course, not detonated, as the violent, sudden effects of detonation would be undesirable. For other purposes, (e. g. torpedoes, blasting, etc.,) it would be a great advantage if it could be made to give more violent explosive effects by a peculiar mode of firing. It has been demonstrated that this can be done, although the best mode of doing it, or whether detonation is actually accomplished, is not known. Experiments in this direction can hardly fail to give valuable results.

Probably a mechanical mixture, like gunpowder, can never be brought by any mode of firing to approach as near to a perfect detonation as the chemical substance nitro-glycerine or gun-cotton; but, even if not detonated, better effects for certain uses may be obtained from it if the proper means are used.

Roux and Sarrau have recently published some interesting results of experiments on the different explosive effects produced by some bodies by certain modes of firing. They divide explosions into two kinds: detonations or *explosions of the first order*, and simple explosions or *explosions of the second order*. Simple explosions are produced either by direct inflammation or by a small charge of gunpowder. Detonations are obtained from nitro-glycerine, gun-cotton, picric acid, and certain picrates, by exploding with fulminating mercury.

Fulminating mercury, they state, does not detonate gunpowder; but if the exploding charge is a small amount of nitro-glycerine, itself detonated by fulminate, then an explosion of the first order is obtained from gunpowder. The relative effects were approximately measured by determining the quantities necessary to rupture small cast-iron shells of nearly equal strength.

The following are among the results given, showing the great difference in force of the two kinds of explosion:

NAME OF SUBSTANCE.	EXPLOSIVE FORCE.	
	First Order.	Second Order.
Gunpowder	4.34	1.00
Gun-cotton	6.46	3.00
Nitro-glycerine	10.13	4.80

**Manner of producing Detonation.**—Detonation is produced by the application of the requisite concussive force by means of a detonating fuse or exploder. A detonating fuse is one which causes explosion by the blow or shock it gives, while the ordinary fuse ignites by simple inflammation. Detonating fuses are generally charged with fulminating mercury, a substance which seems to be specially adapted for this use. With such fuses are fired nitro-glycerine and its preparations and dry gun-cotton. Compound detonating fuses are sometimes employed, such as the "primer," for wet gun-cotton, which is a small charge of the dry gun-cotton, fired by fulminate, and the nitro-glycerine fuses of Roux and Sarrau, mentioned above.

There seems to be for each explosive about a certain amount and kind of force required to effect detonation, which must not be materially departed from.

If the exploder is too weak, inflammation or a feeble explosion only will result; if too heavily charged, it is more likely to scatter

or disintegrate the material acted upon than to explode it. There is also a relation between the mass of the explosive and the charge of the detonator which must be observed. This relation is more marked with some explosives than with others. Thus, nitro-glycerine is a body easily detonated, and the same amount of fulminate seems to fire equally well all usual quantities. If a single particle is detonated, the action quickly extends through the whole mass.

Other substances, less easily detonated, require that as the mass is increased the force applied shall be increased, so that all the particles shall receive a sufficient blow, otherwise only a part will be detonated.

**Comparative Value of Detonation.**—In a detonation we have the fullest *explosive* effect. The suddenness of the explosion concentrates the blow, making it sharp and violent. For certain purposes this is much more effective than would be the same total amount of force more slowly exerted. For instance, in blasting hard rock, the violent explosion will throw out and shatter much more rock proportionately than the slower explosion, which tends to escape in the direction of the least resistance.

Therefore, in blasting with nitro-glycerine, for example, hard tamping is unnecessary. The explosion is too sudden to allow the gases to blow out the tamping and so escape. The effect is consequently equal in all directions. The advantages gained in blasting with nitro-glycerine and its preparations are so great that their use is constantly increasing, in spite of their high cost and the prejudice against them on account of the many accidents that have occurred with them.

In submarine work, such as torpedo firing or removing obstructions, the advantage of the violent explosion is very great. The slower explosion tends to raise or heave up a large volume of water, spreading and weakening the effect; whereas the detonation is more concentrated, tearing its way through the water. Therefore, unless actual contact of the charge with the object can be obtained, it is advantageous to use a detonating explosive; since its action, although perhaps more local, is much less weakened by the layer of water through which it passes.

In general, when a scattering, tearing effect is desired, the detonating explosive must be used.

**Relative Force of Explosive Bodies.**—The experimental determination of the actual force exerted by explosive bodies is very difficult, particularly with those that detonate.

As Sprengel remarks, "It is to be regretted that no exact method exists for comparing the force of detonating explosives."

Sarrau considers that the force of an explosive substance is nearly proportional to the product of its heat of combustion by the weight of permanent gas given off on explosion; he calculates the force of some explosive substances, and thence derives the following table, showing the relative force they exert. In this table, the force exhibited by powder is taken as unity, and is the mean of detonations made with five varieties.

NAME OF SUBSTANCE.	RELATIVE FORCE.
Saltpetre powder . . . . .	1
Chloride of nitrogen . . . . .	1.08
Nitro-glycerine . . . . .	4.55
Gun-cotton . . . . .	3.06
Picrate of potash . . . . .	1.98
Mixture of 55 parts picrate of potash and 45 parts saltpetre . . . . .	1.49
Mixture of equal weights of picrate and chlorate of potash . . . . .	1.82

Theoretical comparisons of force do not, however, indicate accurately relative effects as found in practice. If the character of the chemical change that occurs in an explosion is perfectly known, then the total amount of force exerted may be calculated, but the manner in which this force is exercised is of great importance in determining the actual effect obtainable.

This brings up again the second of the conditions of explosive character in reaction; viz., the time required for the change. Thus, the explosive force of one body is so rapidly exercised that

it may be entirely utilized, while another acts so slowly that considerable force is lost or not used in certain circumstances of practice.

If perfect detonation was accomplished in every instance, then the actual force exhibited would approach very nearly the theoretical proportions. But, as explosive bodies differ in their manner of action, comparisons of force will vary according to the mode of comparison employed.

For example, supposing Sarrau's table to be theoretically correct, it will at once be noticed that according to it nitro-glycerine and gun-cotton do not exceed gunpowder in as great a degree as they do practically. This is because, under the circumstances in which these bodies are used, the force they exert is more completely utilized than can be that of powder under the same circumstances. Again, there may be conditions in which powder will be proportionally more effective than the quicker burning explosives.

In the same table, chloride of nitrogen is given as having but a trifle more force than gunpowder; yet the explosion of chloride of nitrogen is so sudden and violent that destructive effects may be produced with it far surpassing anything that can be accomplished with gunpowder under the same circumstances.

Therefore, whatever may be the relative force *possessed* by the different explosive substances, we must depend for a knowledge of their *comparative value* upon the results of practice; and it will be found that relative values will vary very much with the conditions of use.

**Methods of Testing the Strength of Explosives.**—Several methods have been devised for the purpose of testing the strength of the various explosives, but as yet none can be said to give perfect satisfaction. All of them are approximations, nor do the inventors claim more for them. Moreover, the majority of the methods suggested seek to determine merely the comparative strength of the explosives, some one powder being selected as the standard with which all others are compared. It still remains to institute an absolute scale by which the strength of explosives may be measured.

**The Iron Plate Test.**—This test consists in estimating the strength of a powder by its effect in smashing an iron plate of standard thickness and tenacity, when exploded in certain charges on its surface. This method is still retained in the Austrian service.

It is evident that the precision of this test must depend upon the quality and uniformity of the iron; and it cannot be considered a safe absolute standard. For instance, trials at Willets Point with a superior quality of metal gave the following results, the prescribed conditions of the Austrian test being exactly fulfilled. With a charge of 3.7 ounces the included angle was  $131^{\circ}$ ; with 4.3 ounces it was  $126^{\circ}$ , the back of the plate showing incipient cracks; with 5.0 ounces the angle became  $60^{\circ}$ , the back of the plate being broken. The blow in this test is so sudden that the bending seems to be governed by the number of overstrained fibres.

The experiments of Professor Abel, in England, a few years ago, showed that under these conditions, which differ so radically from those of a charge when confined, weak powders often showed to better advantage than strong ones. In fact, that, instead of being a test of the available strength of the explosive, it was in reality a test of the completeness of the detonation under exceptional circumstances.

**The Mortar Test.**—The comparison of ranges attained by shot fired from short mortars, or *éprouvettes*, when charged with different explosives, is no more accurate than the iron plate test for measuring the strength of such powders.

It is undoubtedly more reliable than the test just mentioned for the lower nitro-glycerine powders, but does not meet the requirements when applied to the high grades. Ballistic effect and explosive effect are not necessarily related by direct ratio. To develop velocity in a projectile, a certain time is necessary to communicate the motion by the molecular springs to all its parts.

A continued force, such as is obtained from the explosion of gunpowder, accomplishes this result much more effectively than sudden explosion of gas resulting from explosion of a high explosive. The mortar test, therefore, is unfair to the high powders, the difference shown in their favor not being sufficiently great.



General Abbot, of the U. S. Engineer Corps, in his extensive report on submarine mines, discusses at considerable length the various plug compression tests. His investigations were carried out with great exactness and the results obtained by him have, for many years, formed the basis of calculation in all submarine work undertaken by the Engineer Corps.

A full description of the apparatus used, the methods of measurement, together with a full discussion of the final results, is contained in the report referred to.

**The Quinan Pressure Gauge.**—In all practical work at the U. S. Artillery School, in which the strength, or explosive force of explosives is to be determined, the Quinan Pressure Gauge is used, both on account of the degree of accuracy with which it registers the pressures developed by the explosives, or rather "by the gases resulting from the decomposition of the explosives," and because of the ease with which the apparatus is manipulated.

The instrument used in the following experiments consists of a heavy block of wood, upon which is bolted a cast iron block or base. In this base are inserted four wrought iron guides or standards, set around the circumference of a four inch circle. A steel plate is let into the iron block flush with its upper surface. A ring holds the guides in place at the top, their ends being reduced to screwbolts passing through the ring, which is held down by nuts.

The piston, which rests upon the plug or cylinder of lead (to be compressed) is a cylinder of tempered steel, four inches in diameter and five inches in length. It is turned away at the sides to lighten it as much as possible. It moves freely between the guides. In the top of the piston is a parabola-shaped cavity to hold the charge of explosive. The weight of the piston is twelve and one-quarter pounds. The shot, made of tempered steel, is four inches in diameter and ten inches in length, weighing thirty-four and one-half pounds. It is bored through its axis to receive a capped fuse.

To operate the instrument, a plug or cylinder of lead is placed upon the steel plate within the guides. The piston is put down gently upon it and the charge of explosive placed in the cavity.

The shot is next lowered gently upon the piston and the capped fuse pushed down through the hole in the shot. The fuse being lighted, the charge is exploded when the fire reaches the cap, throwing out the shot and compressing the lead plug. The accuracy of the test is based upon the assumption that the lead plugs shall be of uniform density and homogeneous in structure. The form of plug adopted was a cylinder, one inch in diameter and one inch in length. In regard to the kind of plug, the choice lay between plugs cast in moulds and plugs cut from a solid bar which could be obtained of the desired dimensions in the factories. This bar, though not made of perfectly pure lead, is manufactured from large masses of metal at a high temperature, is very dense and can be obtained in lengths of fifty feet.

"It was decided that the desired uniformity would be more likely to obtain in this product than in plugs cast one at a time from small masses of metal. Having prepared plugs of both kinds, the next point was to test their relative merits for the object in view. The nature of this test was fixed by an additional and independent consideration. It should be borne in mind that, while being compressed by the explosion in the pressure gauge, the lead surface opposed to the piston continually increases.

"It is evident, therefore, that the amount of compression shown by the plug is not a direct measure of the strength of the explosive.

"For example: if one powder exploded in the pressure gauge compresses a plug  $\frac{2.50}{1000}$ ths of an inch, and another powder compresses a plug  $\frac{5.00}{1000}$ ths of an inch, the latter powder would be twice as strong as the former if the compressions were direct measures of their relative strengths, but from what has preceded, it is evident that the second is much more than twice as strong as the first powder, and the difficulty arises in determining the relation existing between the two."

As a practical measure of the strength, Mr. W. R. Quinan, the inventor of the gauge, to whom I am greatly indebted for valuable information on the subject, assumed that it was proportional to the work performed in reducing the height of the lead cylinder.

To get an expression for the work, Mr. Quinan determined, by means of a simple apparatus, the number of foot-pounds required to produce the different amounts of compression, and graphically represented the relations existing between the plug compressions and foot-pounds by means of a diagram, which was constructed, using the compressions as the ordinates, and the foot-pounds as the abscissas of a curve. The extreme co-ordinates were fixed by nitro-glycerine.

While the results registered by the pressure gauge are very reliable as comparative measures for high explosives, they are not equally true and accurate for the lower class. "A triple charge of good black blasting powder, fixed with a fuse, will produce a scarcely perceptible effect on the plug, and yet we know that this powder is capable of great work under certain conditions.

"We may suppose, without an error affecting our principle, that in firing twenty-four grains, or 1.555 grammes, of high powder, the product of the amount of gas, multiplied by the temperature of the gases, gives a number equal to the product of the corresponding elements in the explosion of thrice the charge of black powder. But in one experiment we get a compression which is almost infinitely greater than in the other; for in the last we get a result too small to be measured. It is because the third factor in one formula for explosive effect, *time*, bears a similar but inverse ratio in the two cases: in the first being inconceivably short, and in the second case a sensible interval.

"In the explosion of the black powder, the force, though great, is developed so gradually that at no one instant is sufficient inertia developed in the shot to produce a sensible compression of the lead."

(Report on Vigorit Powder, by Wm. R. Quinan.)

Several of the subjects mentioned in this lecture will be again referred to subsequently, especially the phenomena attending detonation and the theoretical efficiency of various explosives. At present it is only necessary to consider so much of the subject as will assist us in our practical work.

**Constitution and Classification of Explosives.**—Although the classification of explosives given by Berthelot is too theoretical to be of any great use practically, it will be interesting to note the unlimited nature of the subject from an abstract point of view. According to Berthelot ("Sur la force des matières explosives"), every system of bodies capable of developing permanent gases, or substances which assume the gaseous state by reason of a reaction, such as water above  $100^{\circ}$  C., mercury above  $360^{\circ}$  etc., can constitute an explosive agent.

Gases themselves become explosive, if they are compressed beforehand, or rather if their volume increases in consequence of some transformation. It is not however indispensable that the temperature of the system be raised; although that condition is generally fulfilled, and it tends to increase the effects.

However, this definition of explosive agents, exact from an abstract point of view, is too general for practice. Practically those systems only are used which are susceptible of a rapid transformation, accompanied by a great disengagement of heat.

Moreover the initial system must be capable of existing by itself, at least for some little period of time; its transformation taking place only when provoked by some external cause, such as friction, ignition, shock, or the intervention of a chemical agent, either causing reactions which are propagated chemically ( $\text{H}_2\text{SO}_4$  in the presence of a mixture of  $\text{KClO}_3$  and organic substances); or causing a sharp shock, which by its mechanical effects leads to the production of the explosive wave and detonation in general.

**General list of Explosives.**—Let us enumerate the explosive bodies which fulfil these conditions. They may be classified in eight distinct groups as follows:

*First Group*:—Explosive gases, such as

1. Ozone, Hypochlorous acid, the gaseous oxyacids of chlorine, etc., which detonate under very slight influences, such as slight heating, or sudden compression.

Other subordinate elements are often present; in gunpowder for instance, the potassium binds the nitrogen and oxygen loosely together in the state of saltpetre, and there is sulphur, a second combustible, whose oxidation evolves greater heat than that of carbon. When chlorate of potash is present, the chlorine plays the part of the nitrogen, and is set free in the gaseous state.

Two very unstable and practically useless explosive substances, the so-called chloride and iodide of nitrogen, contain neither carbon nor oxygen; but their great violence is equally caused by the feeble affinity of nitrogen for other elements, large volumes of gaseous matter being suddenly disengaged from a very small quantity of a liquid and solid body respectively. An additional and more satisfactory explanation of the explosive force of these and similarly constituted compounds is to be found in the principles of thermo-chemistry—a new and as yet an imperfectly understood branch of science.

For the purpose of instruction, explosives may be conveniently divided into two distinct classes: (1) Explosive mixtures and (2) Explosive compounds.

**Explosive Mixtures.**—The first class consists of those explosive substances which are merely intimate mechanical mixtures of certain ingredients, and which can be again separated more or less completely by mechanical means, not involving chemical action.

These ingredients do not, as a rule, possess explosive properties in their separate condition. There are some however, which might almost be classed in both categories; for example, *picric powder* is composed of ammonium picrate and saltpetre, the former of which contains an explosive molecule, but is mixed with the latter to supply additional oxygen, and thus increase the force.

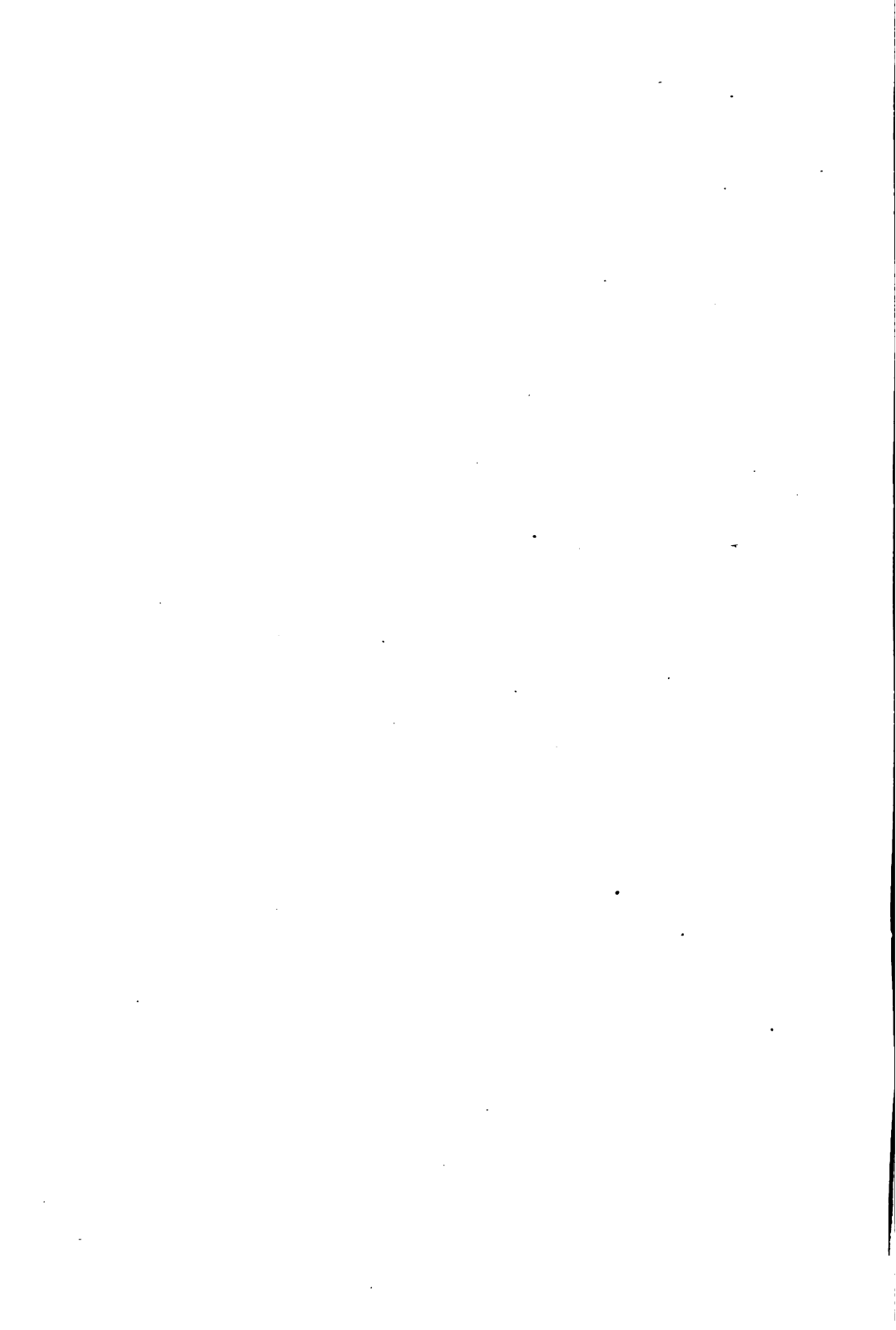
If a substance that will burn freely in air, combining gradually with the oxygen of the atmosphere, be ignited in pure oxygen gas, the combustion will be much more rapid, and the amount of heat generated greater than at the ordinary atmospheric pressure. If it be possible to burn the substance in a very condensed atmosphere of oxygen, we can readily imagine the combustion being very greatly accelerated, and therefore increased in violence; this is what is ordinarily effected by an explosive "mixture." A com-

bustible body and a supporter of combustion are brought into extremely close contact with one another, by means of intimate mechanical mixture; also, the supporter of combustion, or oxidizing agent, is present in a very concentrated form, constituting what may be termed a magazine of condensed oxygen, solid or liquid. In the case of the explosion of a definite chemical compound, the charge may be considered as the resolution of a complex body into simpler forms; this is not, however, always the case where a mechanical mixture is concerned; gunpowder, for example, may be said to contain two elementary substances, C and S, not in chemical union.

**Explosive Compounds.**—In an explosive “compound,” the elements are all in chemical combination, presenting a definite explosive “molecule,” which contains, so to speak, both the combustible and the supporter of combustion, in the closest possible union; we can therefore understand its action being much more sudden and violent than that of the most intimate mechanical mixture.

The chief explosive compounds are formed from some organic substance containing carbon, hydrogen and oxygen, by introducing into it, through the action of concentrated nitric acid, a certain portion of nitric peroxide ( $\text{NO}_2$ ), in substitution for an equivalent amount of hydrogen. A new compound differing outwardly very little, if at all, from the original substance, is thus formed, but in a very unstable state of chemical equilibrium, because of the feeble union of the nitrogen and oxygen in the  $\text{NO}_2$  molecule. A slight disturbing cause brings into play the stronger affinity of the carbon and hydrogen for the large store of oxygen contained in the new compound. Gun-cotton and nitro-glycerine are the leading members of this group, being produced in a precisely similar manner, by the substitution of three molecules of  $\text{NO}_2$  for three atoms of hydrogen (H).

It will be convenient to follow this classification, and to consider the various explosives belonging to each class in regular order, reserving last the consideration of certain explosives which do not properly fall under either of the foregoing classes; and certain others which partake of the character of both classes.



## LECTURE V.

### EXPLOSIVE MIXTURES—GUNPOWDER.

**Explosive Mixtures.**—The chief explosive mixtures may be subdivided into the “nitrate mixtures” and the “chlorate mixtures.”

**Nitrate Mixtures.**—In the nitrates, the oxygen is held in combination with sufficient force to need a powerful disturbing cause to separate it, so that mixtures made from nitrates do not explode very readily, and their action is comparatively gradual; they are not sensitive to friction or percussion, and hence are tolerably safe. Any of the nitrates will form explosive mixtures with combustible substances, but the nitrate of potash ( $\text{KNO}_3$ ) is the one principally employed. The nitrate of soda, called “cubical” or Chili saltpetre, has been used, but absorbs moisture from the air so readily as to give very inferior results. Gunpowder may be taken as the representative of the nitrate explosive mixtures.

**Gunpowder.**—Is a very intimate mixture of potassium nitrate (nitre), sulphur and charcoal, which do not act upon each other at the ordinary temperature, but when heated together, arrange themselves into new forms, evolving a very large amount of highly heated gas. These three ingredients may be mixed in greatly varying proportions, each mixture being explosive, but there must be evidently some particular proportions which will produce the most effective powder.

Experience has shown that a powder containing

$\text{KNO}_3$	. . . .	75	parts
C	. . . .	15	“
S	. . . .	10	“
<hr/>			
100			

is mixed in the best proportions, and until recently the majority of military nations adopted it.



Dr. Debus, in his essay on the "Chemical Theory of Gunpowder" says: "If, therefore, the composition of a gunpowder is required which shall possess nearly the greatest energy and at the same time contain the smallest amount of sulphur compatible with this condition, an experience extending over 500 years has selected a mixture which contains saltpetre, carbon and sulphur nearly in the theoretical proportions."

As gunpowder is a mechanical mixture, it is necessary in order to secure uniformity in the product that the several ingredients should be pure, finely divided and intimately mixed. We shall consider first the preparation of the ingredients and then the manufacture of the powder.

**Refining Saltpetre.**—Refining saltpetre is for the purpose of removing the impurities and all earthy matter which may be present, and is effected by boiling and skimming the rough or crude saltpetre in large open boilers, and afterwards drawing off the liquor and filtering it through canvas bags. The *modus operandi* is as follows: About 2 tons of saltpetre in its crude state are put into an open copper boiler capable of containing 500 gallons; about 270 gallons of water are added to this, or about .66 of water to 1 of saltpetre; these are allowed to stand all night; in the morning a fire is lighted under the boiler, and in about two hours afterward they will have reached a temperature of 300° Fahr. and will be boiling freely.

During ebullition by constant stirring, the light matter, containing many impurities, rises to the surface, and is skimmed off (a little dissolved glue will facilitate the operation). When the skum ceases to rise, cold water is freely dashed on the surface of the boiling liquid to precipitate the chlorides that would otherwise be retained on its surface. After boiling until the solution of the nitrous salts is effected, the fire is allowed to go out; when all ebullition has ceased, the foreign salts and chlorides being the heaviest, are precipitated. The boiler is provided with a false bottom perforated with holes, through which these impurities pass and fall to the bottom of the boiler.

In about an hour after the fire has been extinguished, the temperature of the solution falls to about  $220^{\circ}$  Fahr. A siphon is introduced, the end of which is kept about 1 inch from the false bottom of the boiler, so as not to disturb the sediment. The liquor is drawn off by the siphon into a trough, the bottom of which is fitted with four or five gun-metal taps, communicating with suspended Dowlas canvas filtering-bags, of the shape of an inverted cone. If crystals form on the filtering-bags, hot water is poured over them to keep the canvas open, a constant supply for the purpose being obtained from a vessel provided with a flexible pipe, having a finely-pierced rose-head, placed in close proximity to the filtering-trough. When all the liquor has passed through the filtering-bags, it is run to a cooler about 12 feet long by 6 feet wide by 1 foot deep, lined with sheet copper, and placed by the side of a washing-vat.

The liquor in the cooler is stirred by a wooden rake until the temperature is reduced to about  $180^{\circ}$  Fahr., at which temperature the mother-water separates from the saltpetre held in solution; when it falls below  $180^{\circ}$  a large number of very minute crystals are formed, which are collected and thrown on to a wire-cloth drainer, fixed at an angle immediately above the cooler, that the strainings may run back again into the cooler; the saltpetre, when sufficiently drained, is raked into the washing-vat—also furnished with a false bottom of fine copper-wire cloth.

The whole charge receives three washings; in the first and second, pure water is freely sprinkled over the saltpetre from a rose, and after standing about fifteen minutes the liquor—being very rich in mother-water and saltpetre—is run off into crystallizing pans by a tap at the bottom of the washing-vat. In the third washing the vat is entirely filled with cold water, and the liquor, after standing for about half an hour, is drawn off; it now only contains a small quantity of saltpetre, and is not run into the crystallizing pans, but collected in an underground tank for future use.

The saltpetre obtained by the above process is an almost perfectly pure white salt. It is placed in stone bins perforated with small holes in the ends and sides, where it is allowed to drain.

The saltpetre contains from 7 to 12 per cent. of water, but during the time it remains in the bins about 6 or 7 per cent. is drained off. It is now fit for making gunpowder if used immediately; but if required for storage or transport, it is better to evaporate the remaining water, which is done by drying in a hot chamber in the following manner:

The saltpetre is spread out about two inches thick on shallow trays of sheet copper, and placed on racks in a hot chamber heated to about 260° Fahr., by a flue under the floor. The saltpetre is stirred once or twice; from four to six hours is sufficient to evaporate the remaining moisture. It is taken out and emptied into shallow trays, allowed to cool, and then put into barrels and stored.

By the above process about three-fourths of the saltpetre is crystallized, the remaining portion being held in solution by the mother-water that remains. When this has cooled to within 7° or 8° of the temperature of the atmosphere, large crystals are formed, adhering to the sides and bottom of the cooler, and are collected and put with the grough into the next charge of the boiler; the mother-liquor is collected and pumped into a boiler and evaporated to a fourth of its original quantity, and drawn off by a siphon, passed through filtering-bags, and collected in a receiver, whence it is run into copper pans of thirty-six gallons each and crystallized. The crystals obtained in this manner are pure, but contain cavities of mother-water; it is found best to use them in the next charge as grough.

Over the sediment in the bottom of the evaporating-pan hot water is poured, and the whole well stirred to extract any saltpetre that may remain; after settling, the solution is drawn off and passed through the filtering-bags previous to being run into the crystallizing-pans. Should the filtering-bags become clogged by impurities they are removed and placed in larger bags in a cleaning apparatus, where, together with the bags in which the saltpetre is imported, they are well washed in hot water; this water, containing a small percentage of nitre, is also collected in the mother-liquor tank. The bag-cleanser is also used for washing the skimmings and foreign salts, etc.; the residue with the refuse from the evaporating-pans is sold for manure.

The water from the various washings and drainings is conveyed to the underground tank, pumped into the copper boiler, and is used instead of pure water in the next charge; as it contains a small percentage of saltpetre, a less quantity of grough is required.

**Sulphur.**—Is unfit for use in a crude state; it requires to be refined. This is done by subliming and distilling.

By melting, all earthy matters are left at the bottom of the retort in which the melting is done, the pure sulphur, as vapor, passes upward, and is sublimed and distilled by condensation at two distinct periods of its temperature.

A thick, large, round cast-iron melting-pot or retort is used, built in brick-work with a furnace below. The retort has a movable lid, the joint being made air-tight by clay; the lid is sufficiently large to admit a man for cleaning out the pot. In the lid is fitted a 4-inch plug, tapered for the purpose of charging the retort. Near the top of the retort two pipes branch at right angles, each fitted with a sluice-valve at the end nearest the retort; one of these, the subliming-pipe, from 12" to 14" in diameter, rising at an elevation of  $35^{\circ}$ , is used to conduct the vapor from the retort to the subliming-chamber situated at a distance of about 15 feet from the retort. The chamber is 12 feet in height by 10 feet in diameter at the base, dome-shaped, lined with flag-stones, and the floor covered with sheet-lead. Near the bottom are two doors, the inner of iron, the outer of wood, air-tight, and lined with sheet-lead. Through the bottom of these doors is a small tube leading to a cistern of water, which takes up the sulphuric acid. The outer pipe, from 7 to 8 inches in diameter and 8 feet long, is used in conveying off the vapor at a higher temperature than required for subliming; this inclines downward at an angle of  $20^{\circ}$  delivering the vapor into a receiving-tank inclosed in an outer jacket; cold water from a cistern circulates through them, through an annular space about 1.05 inches in width. The water enters the jackets at their lowest points, and passes off at their highest, near the retort.

The receiving-tank fitted with a movable lid somewhat similarly arranged to that of the retort, has a plugged hole in the center, through which a rod is introduced for guaging its contents. A

small pipe fitted to the top of this tank conducts any non-condensed vapor to a chamber where the "flowers" are precipitated. This chamber is occasionally cleaned out by a small door. A discharge-valve is fixed to the bottom of the receiving-tank for drawing off the sulphur into molds.

About  $6\frac{1}{2}$  cwts. of crude sulphur are put into the retort, the sluice-valve on the subliming-pipe and the plug in the retort-lid left open, the sluice-valve on the distilling-pipe closed, a slow fire applied under the retort; in two or three hours the raw material is melted down.

At  $170^{\circ}$  Fahr., evaporation commences; at about  $200^{\circ}$  Fahr., melting begins;  $239^{\circ}$  Fahr., the sulphur is perfectly fluid; and at  $560^{\circ}$  Fahr., it is ready for distillation. So soon as the melting begins, a pale yellow vapor arises; the plug is inserted in the lid of the retort, the vapor passes to the dome of the subliming-chamber near the top, and falls in a shower of very fine condensed particles termed "flowers of sulphur."

After two or three hours, as the heat increases, the vapor in the retort becomes a deep reddish-brown color, when the sluice-valve on the subliming-pipe is closed, and that on the pipe leading to the distilling-tank opened, the cold water constantly circulating through the jacket of this pipe and also of the receiving-tank keeps them cool, the vapor rises from the retort and passes along the pipe, becomes condensed, and runs into the tank below, a thick yellow fluid. When nearly all is distilled (which is ascertained by gauging the depth of the liquid sulphur in the tank), the sluice-valve on the distilling-pipe is shut, the fluid in the receiving-tank allowed to cool for an hour or two, when it is run off by the valve to molds, and allowed to cool and solidify. These molds are used wet, otherwise the sulphur will adhere on solidifying. When cool, the refined sulphur, broken into lumps, is ready for use. The vapor remaining in the retorts passes into the dome of the subliming-chamber, where it is evaporated as "flowers." The earthy matter in the retort is afterward cleaned out.

The "flowers" of sulphur are unfit for making gunpowder, on account of the acid they contain, unless required for fireworks or composition. They are returned to the melting-pot with a fresh charge. The crystalline, or distilled sulphur, only is used in making gunpowder.

**Charcoal.**—Charcoal, the residue after wood has been charred, as an ingredient of gunpowder, is next in importance to saltpetre. When uniformity in quality of gunpowder is required, great care must be exercised in its preparation, for the chemical composition of charcoal—*i. e.*, the percentage of carbon contained therein—will affect the quality of the gunpowder to a considerable degree; therefore, extreme care has to be exercised in charring the wood. Gunpowder should contain not less than 15 per cent. of charcoal.

Much depends upon the quality and condition of the wood employed; the sap should be thoroughly dried in the wood to secure the best quality of charcoal; this end is attained by desiccating newly-cut timber in a hot chamber for ten or twelve days, although it is questionable if the charcoal so obtained is as good as that produced from wood that has been seasoned for a number of years. Small wood, perfectly clean, free from bark, quite dry, are essential requisites for making good charcoal.

The kind of wood commonly used is that of the willow species—the common white Dutch willow, the poplar, and the alder are generally preferred; other woods are, however, frequently used, and for a first class strong powder, black dogwood is said to be best, but its great cost prevents its being largely adopted.

Distilling the wood in retorts is the method usually employed for procuring a light and equal quality of charcoal; pit-burned charcoal is, however, preferred for fuse, pyrotechnic compositions, etc., on account of certain qualities it possesses. The method of distilling in retorts is as follows: A number of retorts are set in brickwork at a suitable height from the ground floor, under which a furnace is provided; the bottoms of the retorts are protected from the direct and intense heat of the furnace by a fire-brick lining, through openings in which, and by flues, the flame passes round the retorts before reaching the chimney. The wood must be small, of eight or nine years' growth; it is obtained early in the

fall, its bark entirely removed, cut into lengths of about 6 inches and stacked for drying. When thoroughly dried it is put into a sheet-iron cylinder or "skip," having a movable lid or door at one end, which is placed horizontally on an iron carriage corresponding in height with the door of the retort; the carriage is run forward to the mouth of the retort, the cylinder containing the wood slid into the retort, which is fitted with an air-tight door, and which has been previously heated to a dull red heat.

The process of charring commences, the steam, tar and gas in the wood pass from the cylinder by holes in the door, through a pipe to the furnace and are consumed. From three to four hours are required to completely char a cylinder of wood. The cylinder with its contents is drawn out of the retort by a block and tackle, lowered into an air-tight cooler with a close-fitting lid, and allowed to remain for about half a day; it is then placed in a smaller cooler, where it remains until cold. After the charcoal has been carefully picked, it is fit for use in making gunpowder. About three charges can be burned in each retort every twelve hours.

A good and uniformly pure charcoal has, if properly made, a jet black appearance; the fractures show a velvet-like surface, and appear the same in both large and small pieces. It should not scratch soft polished metal, and if treated with distilled water there should be no appearance of alkali.

From 20 to 25 per cent. of charcoal is obtained from willow and alder, and from 25 to 30 per cent. from black dogwood; the latter is very dense, tough, and of slow growth, its usual size being about one inch in thickness. When charred, it has a yellowish looking surface, and is slightly metallic in appearance.

The kind of wood from which the charcoal has been made is known by the pith; that of dogwood is circular and large for the size of the wood; that of the willow is also circular, but somewhat smaller; that of alder forms a figure of three equidistant radial lines.

Charcoal is very porous, and quickly absorbs moisture; therefore a great store is never kept. Previous to use, it is very carefully examined and picked, uncharred pieces being excluded.

To test charcoal for an alkali, finely powder a small quantity and boil it in distilled water, filter and test with litmus paper reddened by weak acid. Should the charcoal contain alkali, the paper will be partially or wholly restored to its color.

*Pit-burned charcoal* is used in the manufacture of "pit gunpowder," and is suitable for filling fuses, port-fires, etc.; it is also used for pyrotechnic compositions, and such purposes.

**Charcoal Grinding Mill.**—Before the ingredients are mixed together, they must be pulverized or ground to a fine powder. Charcoal after standing a fortnight is ground in an apparatus somewhat similar to a coffee-mill on a large scale. The mill consists of a cone secured on a vertical spindle provided with teeth running spirally over its entire outer surface; the cone revolves in a cylinder provided with teeth on its inner surface; these teeth are spiral also, but incline in the opposite direction to those on the cone.

The revolving cone is adjustable in a vertical direction to increase or diminish the space between its teeth and those of the fixed cylinder; thus a coarse or fine charcoal is produced at will. The adjustment is effected by means of two hand-wheels working on a fine screw-thread cut upon the small vertical cone spindle, which spindle can be moved upward or downward by means of the hand-wheels through the large hollow shaft upon which the bevel driving-wheel is keyed. Motion is communicated from this shaft to the small one by means of a feather upon the surface of the latter, which fits and works in a groove cut in the inside of the hollow shaft. The small hand-wheel is used for locking and securing the larger one in any required position.

The hopper above receives the charcoal. On the under side of the cone, and revolving with it, are a couple of arms, that carry the ground charcoal to the discharge spout on one side of the fixed cylinder and conduct it to a sifting reel; this reel is simply a skeleton cylinder of wood, covered with copper wire cloth, having fine meshes thirty-two to the inch.



The sifting reel is driven by a pair of bevel wheels set at a slight angle to allow the charcoal to run readily along the interior; as it revolves, it causes the particles of charcoal to be continually rolling over each other and covering new surfaces of the reel; the fine particles pass through the meshes of the wire cloth and fall into a receiving bin, whilst the larger ones are thrown out at the lower end of the reel to another bin, whence they are taken and returned to the hopper. The reel and bins are inclosed entirely in a wooden framework and covering, so as to prevent the dust, which is very light, from spreading over the house. Doors are provided in this wooden covering, by means of which the ground charcoal can be removed.

After being ground the charcoal stands for about eight or ten days before using it; owing to the readiness with which it absorbs oxygen when in the pulverized state, it is apt to become heated, and spontaneous combustion to ensue. The danger from this cause is much lessened when it is stored in small quantities and in separate iron cylinders or bins.

**Saltpetre and Sulphur Grinding Apparatus.**—The saltpetre, if used immediately after being purified, is so fine as to require no further reduction of its particles before mixing; but if it has been dried for storage it must, like the sulphur, be reduced to a very fine powder. They are ground separately in a small machine somewhat similar to a mortar-mill. The machine consists of a pair of edge rollers traveling round a strong circular cast-iron bed, revolving at the same time on their own axis.

The speed of these rollers is eight revolutions per minute round the bed; they are each 4 feet in diameter, and weigh 30 cwt. Each one travels on a different path, one being near to the inside curb, or "cheese," as it is technically called, whilst the other is farther away from the centre. A shaft or spindle common to both passes through their centers, and between them is a cross-head fixed on a vertical shaft driven by means of bevel gearing, the pinion being secured on the main horizontal driving shaft underneath the machine, whilst the vertical shaft, upon which the large bevel wheel is fixed, passes through the cross-head; this latter

being provided with suitable brass bushes, in order to allow the rollers to rise or fall according to the thickness of the material under them.

The material to be ground, whether saltpetre or sulphur, is spread evenly over the bed of the machine to a thickness of about 1.50 or 2 inches; the rollers are then set in motion. A very short time suffices to complete the operation. The material, when ground, is shoveled from the bed into tubs and emptied into a hopper placed above a sifting reel which is similar in all respects to the charcoal reel. As the reel revolves, certain projections provided on the shaft strike against similar projections on the bottom of the trough that conveys the material from the hopper to the reel, and as this trough is slung under the hopper it is made to vibrate and cause the material to be shaken gradually from the hopper to the reel. The fine particles pass through a wire cloth of thirty-two meshes to the inch and fall into a bin provided; the coarse particles are thrown out at the end into another bin, whence they are taken and reground.

The ingredients are now ready for the manufacture of the powder.

**Manufacture of Gunpowder.**—The manufacture of gunpowder consists of the following processes:—(1) mixing the ingredients; (2) incorporating, or “milling”; (3) breaking down the mill-cake; (4) pressing; (5) granulating, or cutting the press-cake; (6) dusting; (7) glazing; (8) second dusting; (9) stoving, or drying; (10) finishing.

*Mixing the ingredients.* The ingredients are carefully weighed out in the proper proportions for a 50 pound mill-charge, with an extra amount of saltpetre according to the moisture found to be contained in it; they are then placed in the mixing machine, which consists of a cylindrical gun-metal or copper drum, with an axle passing through its centre, upon which is disposed several rows of gun-metal fork-shaped arms, called “flyers”. When in operation, the drum and “flyers” revolve in opposite directions and at different rates of speed.

After being mixed in this machine for about five minutes, the composition is passed through a hand-sieve over a hopper, falls into a bag placed below, and is tied up ready for the incorporating mill. It is now called a "green" charge.

*Incorporating or Milling.* The incorporating mill consists of a circular iron bed, about 7 feet in diameter, firmly fixed, upon which revolves a pair of cast-iron cylindrical edge runners, the edges of which are now usually surface-chilled. The diameter of the runners is about 6 feet, and their width 15 inches; they have a common axle which rests in gun-metal bouches in a solid cross-head attached to a vertical shaft. The shaft passes through a bearing in the centre of the bed and by a system of gearing is driven by machinery which, in the latest steam mills, is placed beneath the bed in cast-iron tanks. Each runner weighs about 4 tons, and travels with the average speed of about 8 revolutions per minute. The bed has a sloping rim on the outside called the curb, and on the inside an edge formed by the "cheese," or bearing through which the shaft passes. The runners are not equidistant from the centre of the bed, one working the part of the charge near the centre, the other the outer portion; their paths, however, overlap. Two wooden leather-shod "ploughs" attached by means of arms to the cross-head, one working next to the shaft and the other close to the curb, throw the composition under the runners.

The charge is spread evenly over the bed with a wooden rake, and contains about 2 pints of water; additional water (from 2 to 6 pints) is added from time to time, according to the state of the atmosphere. This is done for the threefold purpose of preventing powder dust from flying about, facilitating the incorporation, and reducing the effect of an explosion in case of an accident.

During the process of incorporation, a millman enters the mill occasionally, takes a wooden "shover," and pushes the outside of the charge into the middle of the path of the runners, to insure uniform incorporation of the entire charge. The action of the runners is a combination of rolling and twisting, and has, on a large scale, somewhat the effect of a pestle and mortar, crushing, rubbing, and mixing the ingredients, thereby effecting an intimate union.

The time of milling depends upon the nature of the powder. For good fine-grained powders it varies from 4 to 8 hours; the very best sporting powders require 12 hours under the runners; blasting and cannon powders are incorporated from 2 to 4 hours.

This process demands the utmost care and attention and should be conducted by experienced men, as the quality of the powder depends entirely upon this operation, and no subsequent treatment can remedy imperfect or defective incorporation.

When the ingredients have become incorporated, the product is known as "mill-cake," and it should be homogeneous in appearance, without any visible specks of sulphur or saltpetre, and of a dark greyish or brownish color, according to the charcoal used.

The mill-cake is carefully tested to ascertain whether it contains the proper amount of moisture. This should be from 2 to 3 per cent. for fine grained powders, and from 3 to 5 per cent. for powders of larger granulation.

There is greater danger of an explosion during the incorporation than in any process of manufacture. The millmen only enter the mill occasionally to "liquor", or shift the charge on the bed. The building itself is made as light as possible, the roof, and front and rear sides being constructed of very light boards, or even of canvas on wooden frames, while the partitions between each pair of rollers are of solid masonry or heavy brickwork. Directly over the bed of each mill is a flat lever-board, or "shutter" in gear with a tank of water, so arranged that when the shutter is raised on its pivot by an explosion, the water is upset into the bed; a horizontal shaft connects all the shutters in a group of mills, so that the explosion of one mill at once drowns all the remaining charges. The tanks can also be overturned by hand.

*Breaking down the mill-cake.* After removal from the incorporating mill, the mill-cake is broken down, or reduced to powder meal, so that it can be loaded into the press box.

The breaking-down machine consists essentially of two pairs of gun-metal rollers, set in a strong frame of the same material, one roller in each pair works in sliding bearings connected with a weighted lever, so that a hard substance can pass through without

any dangerous friction. An endless canvas band, with transverse leather strips attached, conveys the pieces of mill-cake from a hopper to the top of the machine, where it falls between the first pair of rollers; after passing through the second pair of rollers which are directly below the first, the meal falls into wooden boxes, which are placed upon carriages, and conveyed to small magazines, whence it is taken to the press.

*Pressing.* The last operation and that of pressing the meal into a solid cake is for the purpose of fitting it to be made into a hard grain of uniform density.

The powder is brought from the small magazines to the press-house where it is compressed into hard slabs, or sheets.

The press-box is usually of oak, with a strong gun-metal frame, and so constructed that three of the sides can turn back on hinges, or be screwed firmly together. To introduce a charge of powder meal into the box, it is laid sideways, the top being temporarily closed by a board, and the uppermost side alone being open, and gun-metal plates are placed vertically in the bore, being separated by narrow strips of wood, or racks, the distance between the plates being regulated by the particular kind of gunpowder required in the final product.

The meal is poured between the plates and rammed evenly, and the racks are then withdrawn.

The remaining, or upper side of the box is screwed on, and the box is turned up into a vertical position, and placed on the table of the hydraulic ram directly under the fixed press-block. The pumps (which are in a separate building) are now set in motion, and the press-block allowed to enter the box. In the most improved presses, as soon as the block has reached the point to which it is desired to compress the powder, the edge of the block releases a spring and rings a bell as a signal to stop the pumps. The powder is kept under pressure for a few minutes, after which the ram is lowered, and the box removed and unloaded.

The above mode for regulating the pressure is found to give more reliable results than trusting to the indicator gauge of the hydraulic press, for the reason that the elasticity, or resistance to pressure, of the meal varies with the amount of moisture in it, and the state of the atmosphere.

In order to secure uniform density, equal quantities of meal, containing equal amounts of moisture, must be pressed into the same space. In practice, however, the moisture in the meal will slightly vary, whatever care be taken with the mill-cake, owing to the varying hygrometric condition of the atmosphere by the time each charge comes to the press.

It is therefore necessary to alter the exact distance the press-block is allowed to enter the box, not only with the nature of the powder, but with the season of the year, and even according to the prevailing state of weather.

Several objects are sought in pressing the powder meal as above described. First, the cake when made into grain of the required size absorbs less moisture from the air; secondly, the lasting qualities of the powder are greatly increased, especially if glazed; thirdly, after having been compressed, the powder is less liable to be reduced to dust in transportation. Again by a more intimate union, or a closer juxtaposition, of the ingredients, a larger volume of gas is produced, bulk for bulk, than would result from a soft, light powder.

These qualities and others will be referred to again in a subsequent lecture.

*Granulating.* The machine used for granulating the press-cake is somewhat similar in construction to the breaking-down machine.

It consists essentially of three or four pairs of gun-metal rollers fitted with pyramidal-shaped teeth, which are fixed obliquely one above the other in a strong frame work; the sizes of the teeth vary according to the kind of grain required, but decrease regularly from the top to the bottom pair; one roller in each pair works in a sliding bearing with a counter-weight attached to prevent undue friction. Each pair of rollers is connected with that next below by a short rectangular screen of copper wire, while underneath all the rollers are placed two long wire screens fixed in a frame having a wooden bottom; both the frame and the short connecting screens are attached to the machine by strips of lance-wood, and, when in operation, a quick vibratory motion is given to all the screens by means of a polygonal wheel upon the main frame working against a loose smooth wheel attached to the screen-frame.

The press-cake, which is contained in a large hopper, is fed to the top pair of rollers by an endless canvas band, as in the breaking-down machine, and, after passing through these rollers, it falls upon the first short screen; all that is fine enough to pass through is sifted out by the vibratory motion of the screens, and travels down upon whichever screen has meshes fine enough to retain it; the pieces too large to pass through the short upper screen are carried to the next pair of rollers, and so on. At the lower end of the long screens are placed boxes to receive the different sizes of grain; the "chucks," or pieces too large for any grain, are again passed through the machine, while the dust, which falls upon the wooden bottom, and is received in a separate box, goes to the mills to be worked up for forty minutes as a dust charge.

In this machine, as in the case of the breaking-down machine, no iron or steel is exposed, and as little as possible of either metal is used in their construction, the side-frames, rollers, wheels, bolts, nuts, in short all parts, except the shafts and bed-plate, being made of gun-metal, copper, or wood. The floor of the granulating house is covered with soft leather-hide and the shafts are encased in copper or gun-metal.

*Dusting.* The large-grain powder, as it comes from the granulating machine, is called "foul grain" on account of the large quantity of dust it contains, and to remove this dust, the powder next passes through the dusting reels. The reels consist of a cylindrical frame-work about 8 feet long and 2 feet in diameter, covered with a dusting cloth or canvas of from 18 to 56 meshes to the linear inch according to the size of the grain. The reels are either "horizontal" or "slope" according to the position in which they are fixed, or the object in view.

The large grain powders are dusted for about one-half hour in a "horizontal" reel, both ends of which are closed; while the fine grain powders, containing a much greater percentage of dust, are dusted in a "slope" reel, which is open at both ends, and revolves on a shaft fixed at an angle of about  $4^{\circ}$ . The powder is poured in at the upper end of the reel, and is received in barrels placed at the lower end.

*Glazing.* As a general rule, all large grained powders are glazed, and recently nearly all fine grained powders are subjected to the same process, the object being to diminish the formation of dust, and to render the powder less hygroscopic.

The glazing is generally conducted in the same building as the dusting, and the machine consists of a wooden barrel supported by and attached to a shaft running through its centre, and the whole, when in operation, revolves at about 40 revolutions per minute. The barrel is of oak and is about 5 feet long and  $3\frac{1}{2}$  feet in diameter at the centre. The powder is introduced into the barrel through a small door and with it about one-half ounce of graphite or plumbago to 100 pounds of powder. The door is closed and the apparatus set in motion and allowed to run for about 6 hours, at the end of which time, a fine gloss will have been imparted to the grains, and all sharp angles and corners rubbed off.

*Second Dusting.* The operation of glazing always produces a small quantity of dust, which is removed by again passing the powder through a "slope" reel.

*Stoving.* All kinds of gunpowder are dried in the same way. The "stove," or drying room, is fitted with open frame-work shelves, or racks, the heat being supplied by steampipes beneath. The powder is spread upon either copper trays or wooden frames with canvas bottoms (each having a capacity of about 12 pounds) which are then placed upon the racks. The length of time required for stoving depends upon the nature of the powder and the proportion of moisture it contains; it varies from about 12 hours for fine grained powders, to 3 or 4 days for large grained cannon powders; the heat ranges from 120° F. to 145° F. It is all important that the stove should be well ventilated, so that a constant supply of hot dry air may be supplied, and the air charged with vapor carried off; otherwise the moisture would be recondensed upon the powder as the temperature was lowered.

*Finishing.* The drying process again produces a small quantity of dust, which is removed by running the powder for about 3 hours in a "horizontal" reel.



In addition to merely removing the dust, the finishing process imparts to the grains a very smooth glossy appearance, even when no graphite has been used in the glazing barrels. Large grained cannon powders are finished in skeleton wooden reels, and, during the process, a very small quantity of the purest graphite is introduced in muslin bags. Advantage is also taken of this last step in the manufacture of powder to mix together charges of different glazings so as to secure uniform results.

## LECTURE VI.

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### GUNPOWDER—CONTINUED.

**Special Powders.**—For some years, it has been a recognized fact, that the ignition, combustion, and explosive effect of gunpowder depend, in a great degree, on the size, shape, and density of the grain, and that guns of different calibres require for their most efficient service powders differing in these features in order to secure the best results. The rapid increase in weight of projectiles with the increase in calibre of guns, and the comparatively smaller power of resistance of the guns, renders it necessary that the rate of combustion of the charge be regulated, so as to reduce the strains on the guns as much as possible, while at the same time preserving high initial velocity to the projectile, thus rendering practicable the use of the heaviest guns, projectiles, and charges.

The amount of gas evolved at the first instant of inflammation and combustion is measurably controlled by the size and form of grains, offering a less surface of ignition, and the increased density, offering greater resistance to the penetration of the hot gases through the grains, graduates its rapidity of burning. The form of grain affecting the amount of surface exposed to combustion, that shape which offers a comparatively small surface at the first instant of ignition, increasing progressively, is theoretically the best.

Experiments by all civilized nations have settled beyond cavil the important part played by powders suited in the above qualities to the guns in which they are to be used, and have led to the adoption of large-grain powders in heavy guns, resulting in the production, among the best, of *mammoth*, *pebble*, *cubical*, *hexagonal* and *perforated prismatic* powder; the honor of the first investigation and practical results in this direction, being universally awarded to the late General Rodman, Ordnance Department, U. S. Army.

**Hexagonal Powder.**—The hexagonal powder used in guns of large calibre in the U. S. Army is manufactured by Messrs. E. I. Dupont & Co. The uniform size of grain, and their polyhedral shape insure great uniformity in position and size of the interstices in the cartridge; this insures, with a uniform density of grains, uniformity in density of loading, the result being equal and low pressures, together with uniform and good velocities.

**Manufacture of Hexagonal Powder.**—The proportions of the ingredients of hexagonal powder conform to the United States standard, and up to the completion of the incorporation in the wheel mill, its manufacture is like that of ordinary powder.

**Mealing.**—The mill-cake is revolved in a cylinder of wire-woven cloth, with *wooden balls*, until it is *mealed*.

**Pressing.**—The mealed powder is then carefully pressed between horizontal metallic plates or dies. The powder comes out in a sheet or cake of polyhedral granules united along their edges, the dies being nearly perfect dodecahedrons.

**Graining.**—The press-cake is passed between rollers armed with brass cutting teeth at an angle of from  $60^{\circ}$  to  $120^{\circ}$  to the axis, which cut the cake into granules, their cross-section being almost *hexagonal*, whence the powder derives its name.

**Glazing.**—The powder is then sent to the glazing-mill and glazed.

**Brushing.**—The powder is next passed repeatedly through the brushing machine. This consists of a frame with brushes revolving near an inclined plane along which the powder passes by the motion of the brushes.

**Drying.**—The brushing ended, the powder goes to the drying-house where it is dried. The powder is now minutely examined, its specific gravity taken, and a count made of the granulation; a variation of two granules to the pound being enough to condemn the powder.

**Rebrushing and Redrying.**—If satisfactory, the powder is again passed through the brushing-machine, redried, and then receives a third brushing.

**Packing.**—The powder is now packed in barrels and is ready for inspection.

**Prismatic Perforated Cake Powder.**—The adoption of this form of powder by some nations, and production of suitable machinery for its manufacture, necessitated the use of presses of peculiar construction to insure sufficient and uniform density; the press to be so devised as to produce uniform size and shape of grains, and allow their ready withdrawal from the molds; the surfaces such as to allow close packing in a given space. These considerations led to the adoption of a regular geometrical figure; the hexagon offers a good shape for piling, the angles being all sufficiently obtuse to prevent breaking or spawling at the edges. Each layer and the whole cartridge is easily made up. Perforations were found necessary to insure better and more uniform control of combustion in the grain. The number of perforations first adopted was seven—one central, the other six at equal distances from the central one—although one perforation in the center has been found sufficient.

The ingredients for the manufacture of the powder-base are the same as used in manufacture of ordinary powder. The pulverized materials for 220 pounds are placed in a wooden drum lined with sole-leather, with 330 pounds of bronze balls, and subjected to 1,440 revolutions at the rate of 8 or 10 per minute. The powder is then brought to the moistening table of wood surrounded by an upright edge, over which is suspended a graduated glass measure having a copper pipe and rose at the bottom. On the table a charge of 55 pounds of powder is spread and moistened with  $2\frac{3}{4}$  quarts of distilled water. It is then passed from a hopper to an endless canvas belt 20 inches wide, between a lower paper and upper bronze roller, weighing 2,425 pounds, making a revolution in twelve minutes. The bronze roller can be weighted to exert a pressure of 60,000 pounds. The powder is then broken into coarse lumps by wooden mallets, and granulated to two sizes of grains; the first, cannon powder—used for manufacture of the prisms—is passed through a sieve of 0.26 inch diameter of holes.

**Manufacture of Perforated Prismatic Powder.**—Ordinary grain powder, made as above, is of a specific gravity of 1.5, and too elastic for use in the press. By reworking, it loses a part of

its elasticity, and is then fit for formation of the prisms by the following process: The powder-base, as above, is moistened with 10 per cent. of water, passed through the spindle press with the prescribed pressure, and granulated grain and dust being collected in a receptacle. This mixture of grain and dust is dried in the air or by artificial heat till  $1\frac{1}{2}$  per cent. of the moisture remains. It is placed in a mixing drum—220 pounds of powder and 330 pounds of bronze balls—and subjected to 1,440 revolutions, moistened and pressed as before, giving it a specific gravity of 1.675 to 1.75. It is granulated and separated, the cannon size again dried, by air till 6 per cent. of moisture in dry weather remains, and placed in barrels covered with damp cloths for use.

The press for this purpose is constructed to give a pressure of 65,000 pounds per square inch. It consists of a heavy casting on a stone foundation; a main and secondary shaft, one fixed and two movable cross-heads. These have each six hexagonal stamps perforated with seven holes, which enter corresponding hexagonal molds on the lower cross-head. Six groups of seven needles are fixed in such position that they extend up through the perforations of the lower stamps throughout into the molds and enter the perforations of the upper stamps as the latter descend to press the powder in the molds; these form the perforations in the prisms. Eccentrics and cranks operating the cross-heads are timed so that when the upper stamps have reached the lowest point of descent, the lower ones are moving upward giving the extreme pressure, after which the upper stamps ascend and the lower ones simultaneously push the perforated prisms up from the molds. The lower stamps constitute the bottom of the molds. The molds are filled from a hopper having a table with forward-and-back motion, containing six suitable measures which receive the powder from the hopper; the charging table moves forward and drops the charge in the molds; its edge carries the prisms brought up from the mold to an inclined shelf, whence they are removed. The capacity of the powder measures can be regulated as desired. Two rooms are required for each press; one for the press, the other for the prisms.

Before starting the press, the mold-needles and stamps and all rubbing surfaces ought to be oiled with a light pure oil or graphite.

All surplus lubricant must be wiped off. The powder to be pressed ought to have at least  $5\frac{3}{4}$  per cent. of moisture. The moist prisms weigh about 620 grains each, and must not vary more than 5 grains. The first two sets of prisms should be rejected because of excess of oil. Three men can work a press; a carrier for every press is also required. The height and weight of the prisms are verified from time to time, and the powder in the hopper is stirred from time to time. Loose powder is brushed away from the stamps and top of the molds; and all rubbing surfaces are lubricated as often as once an hour. If a needle breaks, the press is stopped and the needle replaced. On dry days, the powder loses moisture; this is indicated by increased height of prisms or vibrations of the press, in which case it is moistened with  $\frac{1}{4}$  per cent. of moisture, which is done in a drum by a fine rose sprinkler. The prisms pressed by the press contain about 5 per cent. of moisture, and must be dried to about  $\frac{3}{4}$  per cent. by exposure to air or on shelves in a suitably arranged drying-room; they are then exposed to a temperature of  $120^{\circ}$  Fahr. for 48 hours, and are ready for packing.

The prisms are packed in wooden boxes in layers (12 rows of 11, and 11 rows of 9, 6 deep) weighing about 110 pounds to the box.

The prisms are regular hexagons 0".992 high and 1".6 width across the angles. The packing-boxes are of inch stuff, and may be tin-lined. Two sheets of felt—the smaller at one end, the other on top—keep the prisms from rubbing against each other in transportation.

The boxes have rope handles, and are marked with the weight, kind, place, and date of fabrication of the powder.

**Pellet Powder.**—Pellets are formed by compressing the powder meal into metal molds. Various shapes and sizes were tried; some were flat discs, others prisms, but the shape which found most favor at first was the cylindrical pellet  $\frac{3}{4}$  inch in diameter by  $\frac{1}{2}$  inch in length, and weighing 9.5 grains. Originally these were made by hand, but it was soon apparent, that, if required in

large quantities, machinery would have to be devised for their production; consequently a large machine of somewhat novel description, and capable of making 400 pellets at one time, was designed by Dr. John Anderson, and manufactured in Birmingham.

**Manufacture of Pellet Powder.**—This machine is worked entirely by means of hydraulic power derived from an accumulator, which affords a pressure equal to 1,000 pounds per square inch. The machine consists of two hydraulic cylinders, with a division in the center of each, thus, in reality, making four cylinders; in the two upper ones a plain cylindrical ram is fitted, which merely rises and falls as the water is admitted underneath the ram or is withdrawn. These rams are used, first, for compressing the pellets, and second, for ejecting them, when finished, out of the mold plates. The two lower divisions are fitted with piston rams, securely attached to cross-heads, which are united together, and also connected to two other cross-heads above the cylinders by means of strong wrought-iron side rods, provided with collars working between lugs cast upon the hydraulic presses, and so adjusted as to allow only a certain limited travel either up or down. The upper cross-heads can be adjusted to their exact positions by means of screw threads and lock nuts on the upper end of the side rods. The use of the lower piston rams is to close the upper openings in the mold plates by bringing the top punches, which are connected to the upper cross-heads by a gun-metal plate, down upon the mold plate, and thus confine the powder meal in the molds. The upper rams are now slowly raised, and these, acting upon the lower punches, compress the powder in the mold plate. After the proper density has been secured, the action of the lower rams is reversed, by which means both the lower and upper cross-heads receive an upward motion, thereby raising the upper punches clear out of the way, so as to admit of the compressed pellets being ejected out of the mold plate, and this is done by giving a further upward motion to the two plain cylindrical rams.

To compress the powder in the mold and form a pellet requires four distinct movements of the machine. First, the upper punch is brought down until it rests upon the mold plate and closes the mold; this is effected by a downward motion of the two lower

piston-rams, to which the upper and lower cross-heads are connected together with the upper punches. Secondly, the lower punches are raised by the two upper plain rams, and the powder is compressed in the mold between the two punches. Thirdly, when the pellet is sufficiently compressed, the upper punches are raised from the mold plate, this being done by reversing the action of the two lower piston-rams until the upper cross-head and punches are at a sufficient height to admit of the compressed pellet being ejected out of the mold plate. This fourth and last operation of ejecting the pellet is effected by allowing the upper plain rams to rise still further, and thus force the finished pellet out of the mold by means of the lower steel punches.

It is seen that a machine of this description is capable of making pellets of almost any shape, such as cylindrical, hexagonal, prismatic. or—what is possibly the best of all—spherical, by merely altering the form of the mold and punches. In the machine referred to there are (on a revolving table, the framework of which is made of gun metal), four mold plates fitted; each contains 200 holes, but as there are only two hydraulic presses to the machine it follows that only two sets, or 400 molds, are under compression at one time, so that if we number these mold plates consecutively, then Nos. 1 and 3 will be under pressure whilst Nos. 2 and 4 are being filled. When the powder in Nos. 1 and 3 mold plate is sufficiently compressed, and the pellets formed therein have been removed, the entire table is turned one-fourth of the way round by means of a handle and a toothed pinion working into corresponding teeth provided round the periphery of the gun-metal table. Nos. 2 and 4 mold plates, which have been wholly filled with meal powder, are now brought under the cross-heads of the machine and are in position for the powder contained therein to be compressed into pellets, whilst Nos. 1 and 3 in turn take their places to be refilled; the operation, therefore, of pressing and refilling are continuous, and the machine is capable of producing a large quantity of pebble powder per day and with very little waste.

**Pebble Powder.**—Since the pellet powder was first brought into use, another description of large grain powder, called “pebble powder,” has been introduced for service with guns of large



caliber. The pebble powder is formed of large grains ranging from eleven sixteenths of an inch to as much as 2-inch cubes; to manufacture this class of powder expeditiously and cheaply, has brought forth another description of machine for forming the pebbles by cutting up previously compressed cakes into cubes of the required dimensions. This is done in the following manner:

**Manufacture of Pebble Powder.**—The cake as brought from the press house is of the thickness of the required cubes; this cake the machine has to cut up—first, into long strips of the same width as the thickness of the cake; and, secondly, to cut these long strips transversely into cubes. This is accomplished in the machine by means of two pairs of rollers in the following manner: The cake is fed to a hopper immediately above the first pair of rollers, provided with knives upon their surfaces to cut the cake into long strips. The strips fall on an endless traveling band, which conveys and carries them to the second pair of rollers where they are cut transversely into cubes. Then they drop into a spout, and are delivered to a revolving sifter covered with copper wire, which conveys the cubes to a number of wooden boxes contained in a small gun-metal truck; the dust and small pieces fall through the sifter into other boxes, and are taken back to the press house and worked up again.

**Modifications in the manufacture of Gunpowder.**—Several processes of manufacture have been suggested as substitutes for the old and rather slow method just described and many have been experimented with, but except in cases of great emergency when quantity rather than quality is demanded, the old method has been universally retained.

**Process followed at the Augusta, Ga., Mills.**—In 1862 or 1863 Col. G. W. Rains introduced into the Confederate Powder Mills, Augusta, Ga., a process of mixing which was claimed to be so much more thorough that the time required for incorporation was reduced three-fourths.

The sulphur and charcoal were severally pulverized and bolted;

the nitre (pulverized by disturbed crystallization) was added to these, and the mass, roughly mixed, was moistened with water and introduced into horizontal cylinders of sheet copper, 30 inches long by 18 inches in diameter. These cylinders revolved closely on a common axis consisting of a heavy brass tube 3 inches in diameter, perforated within the cylinders by a number of holes one-eighth inch in diameter. High pressure was introduced through this tube, raising the temperature to the boiling point, while the water produced by condensation, added to that originally used to moisten the materials, reduced them to a semi-liquid slush, which was run out of the cylinders after about eight minutes rotation. On cooling, this mud became a damp, solid cake, the nitre, which in the state of boiling hot saturated solution had entered into the minutest pores of the charcoal, now recrystallizing. The cake so produced was transferred to the incorporating mills, and, under 5-ton rollers, was in an hour brought to the condition of finished mill-cake, ready to be cooled and granulated, while without the steaming process, four hours incorporation in the mills had previously been necessary to produce powder of the same first-class character. The capacity for work of the mills was thus practically quadrupled, the thorough saturation of the charcoal with nitre being accomplished by the steaming, while it remained for the rollers merely to complete the mixture of the whole mass and give the required density to the mill-cake.

**Wiener Process.**—This powder, invented by Colonel Wiener of the Russian Artillery, differs in its manufacture from the ordinary powder in the fact that all of the moisture is eliminated in the press-mill, the mixture here being brought to a temperature of 240° F., the melting point of sulphur. In this manner, equal densities were obtained, but the resulting grains were very porous and consequently had a great capacity for moisture.

**Nordenfelt and Meurling Process.**—This process was devised in order to reduce the danger attendant upon the manufacture of powder. The carbonaceous matter is first ground to a very fine powder, and then the sulphur is prepared for use by dissolving it in carbon bisulphide. The solution is effected by the aid of a gentle heat in a warm bath, and the evaporation of the bisulphide is prevented by covering it with a layer of water.

A saturated or nearly saturated solution is thus prepared. The pulverized carbonaceous matter and the solution of sulphur in  $\text{CS}_2$ , are then thoroughly mixed together in a closed vessel containing a mechanical stirrer. When the mixture is complete, the solution is evaporated or distilled off by the aid of a gentle heat. According to the inventors, when the  $\text{CS}_2$  is evaporated, the carbonaceous matter and sulphur remain intimately mixed, and each particle of carbonaceous matter is impregnated with sulphur, instead of at present where the admixture is obtained by grinding, the particles C and S being mechanically placed side by side. The saltpetre is prepared for use by dissolving it in water; the solution is added to the pulverized carbonaceous matter already impregnated with sulphur as described, and the whole is stirred together in a mechanical mixer.

**Recent Inventions in Gunpowder.**—Besides the changes in the methods of manufacture, there have been several changes proposed in the chemical composition, in the physical condition, and in both chemical composition and physical condition of powders.

**Brown Prismatic or Cocoa Powder.**—This powder was introduced into Germany in 1882, and, on account of the very satisfactory results obtained (superior in almost every respect to those obtained with ordinary cannon powder then in use) it attracted wide spread attention.

Professor Munroe in a report (1884) to the Chief Bureau of Ordnance, U. S. Navy, on the composition of this powder, gives the following results of analysis:

“The powder was in the form of perforated hexagonal prisms color of cocoa, of a hardness of between 2 and 3 on Mohr's scale, and a density reported as 1.86 grams. Qualitative analysis showed the presence of potassium nitrate, sulphur, charcoal and water. The charcoal was of a reddish color and behaved towards alkaline hydroxides like underburnt charcoal. The action was specially marked with ammonium hydroxide as it dissolved out a marked quantity of humus-like substance. Water also yielded a marked amount of infusion.

## Quantitative analysis gave

	I	II	III	IV	Mean.
Moisture	1.05	1.10			1.08
Nitre	80.52	80.36			80.44
Charcoal	15.80	15.99			15.90
Sulphur	2.19	2.26	2.24	2.28	2.24
					<hr/> 99.66

## The charcoal contained

	I	II	III	Mean.
Carbon	48.43	48.17	48.39	48.33
Hydrogen	5.58	5.60	5.53	5.57
Oxygen	44.64	44.93	44.75	44.77
Ash	1.35	1.30	1.33	1.33
				<hr/> 100.00

It is to be seen by these analyses that the cocoa powder differs markedly from the U. S. regulation powder,

1st. In the proportions of the ingredients:

## U. S. Regulation Powder,

Nitre	.	.	.	.	75.00
Charcoal	.	.	.	.	15.00
Sulphur	.	.	.	.	10.00
					<hr/> 100.00

2d. In the character of the charcoal, which is red instead of black.

In order to learn more of the nature of the charcoal, a partial analysis of the ash was made. The ash was red colored. It yielded,

Silica	.	.	.	.	13.93
Ferric oxide	.	.	.	.	25.40
Alumina	.	.	.	.	8.32
Lime	.	.	.	.	28.50
Magnesia	.	.	.	.	7.28
Undetermined	.	.	.	.	16.57
					<hr/> 100.00

The presence of alumina in the ash seems to point to the club moss or some similar lycopodiaceous plant as the source of the charcoal".

It seems a settled fact now, however, that the brown or red charcoal is obtained from very slightly carbonized straw.

The sample examined by Professor Munroe was made at the Rottweil-Hamburg Powder Works at Duneberg, and was marked

$\frac{C}{82}$ .

When tested for ballistic properties it gave fair initial velocity and low pressure, but fouled greatly. A peculiarity of the powder was that it burned so slowly that a grain could be held in the hand, lighted, and then set down before the burning portion reached the fingers. With a single grain weighing 42.4384 grams, the time of burning was 17 seconds. Even when powdered it burns much more slowly than pulverized *black* powder, which would show that the slow combustion was not due to the great density and hardness only.

The Dupont Powder Company of this country has succeeded in producing a brown powder, which compares well with foreign samples. In the American powder, baked wood, which retains its fibrous structure, and a carbohydrate, such as sugar, is substituted for charcoal, while the proportions are as follows:

Saltpetre	.	.	.	78.0	parts.
Sulphur	.	.	.	2.8 to 3	"
Carbohydrates	.	.	.	3.0 to 4	"
Baked Wood	.	.	.	12.0 to 12.5	"

The advantage of the cocoa over other powders exists in its property of imparting a high initial velocity to the projectile, while exerting a relatively low pressure on the walls of the gun. This is due to a number of causes, viz:

1. The form of the grain.
2. The size of the grain.
3. The great density of the grain.
4. The great hardness of the grain.
5. The small percentage of sulphur.
6. The easy inflammability of the charcoal or carbohydrates.
7. The relatively great heat evolved.
8. The simplicity of the chemical reaction as shown by Noble.

(5) Tends to reduce the readiness with which the powder will ignite or raises its point of ignition, even when the grain is pulverized.

(1), (2), (3), (4) and (5) combined, operate so long as the first four exist to produce a very slow rate of combustion. By the time, however, that the projectile is moved from its seat, the grains will be reduced in size and more or less broken up. We then have a finer grained powder which is highly inflammable at the temperature which exists, and consequently the volume of gas evolved will increase rapidly as the volume of the chamber increases. Owing to the relatively great amount of heat evolved (7), the cooling effect of the envelope is less marked than with other powders. From the comparatively simple chemical reaction, it is probable that the rapidity of the reaction is more uniform than in the more complex reactions, resulting from the explosion of other powders.

According to Berthelot, dissociation plays an important part in explosive reactions; this is probably the case with powders made from underburnt charcoal, as this contains carbohydrates, or with those in which a carbohydrate is a constituent.

**Amide Powder.**—F. Gaens has proposed and patented the use of a gunpowder differing from the old gunpowder, still more radically in composition than brown powder does. It consists of

Potassium Nitrate	.	.	.	101 parts.
Ammonium Nitrate	.	.	.	80 "
Charcoal	.	.	.	40 "

The theory is that when these components are employed in suitable proportions, *potassamide*  $K H_2 N$ , is formed on ignition of the powder, that the *potassamide* is volatile at high temperatures and increases the useful effect of the powder. The reaction is represented as follows:



The patentee claims for this powder that when burned, it leaves very little (if any) residue, produces no gases injurious to the gun, and much less smoke than ordinary gunpowder does. This proposal is very interesting, and the advantages claimed for the powder are most important; but there is no statement in chemical literature of the existence of a *potassamide* volatile as such.

The explosive reaction resulting from such a mixture would probably be represented as follows:

$2 \text{KNO}_3 + 2 (\text{NH}_4) \text{NO}_3 + 6 \text{C} = \text{K}_2\text{CO}_3 + 5 \text{CO} + 4 \text{H}_2\text{O} + 3 \text{N}_2$ ,  
the products being those resulting from the explosion of ordinary gunpowder, the ammonia being oxidized into water and nitrogen; there would also be some inter-reaction between carbonic oxide and water vapor at high temperature, with the formation of some  $\text{CO}_2$  and  $\text{H}$ . The volume of total gases produced by the ignition of such a powder would be very large, and its rate of burning would be likely to be slow (from the absence of S).

Krupp's report of October, 1888, contains an account of trials of new kinds of powder furnished by the United Rhenish-Westphalian powder factories. These were of two kinds, a large grain and a prismatic powder; their composition is not given, but from the properties attributed to them of giving but little residue, thin smoke, and of being highly hygroscopic, it is very probable that they contain  $(\text{NH}_4) \text{NO}_3$ , and are similar to Gaen's Amide Powder. The grain powder, suited for use in guns of small calibre, was tried in guns of 4 to 8.7 centimetre calibre (1."58 to 3."42) and found to give considerably less pressure in the powder chamber for equal velocity than the German service grain and cubical powders which were tried in comparison, the new powder being stated to be about  $1\frac{1}{4}$  to  $1\frac{1}{3}$  times as efficient as the old.

The prismatic powder suited for medium sized guns, was proved in 10.5 and 15 centimetre guns (4."13 and 5".9), with the result that the new powder was found to be more efficient per unit of weight than the *brown prismatic powder*, giving less pressure for the same velocity; and it was stated that, without exceeding a safe limit of pressure, the new powder could give velocities which could not be reached by the brown prismatic powder.

**Quick Powder.**—Mr. G. Quick has taken out several patents for improvements in cartridges for ordnance. The first (1884) is for the pressing of disks or cakes of gunpowder (or other gas-producing explosive) with a large central cylindrical hole and smaller radial one, which are connected by numerous radial and concentric channels, either formed on the flat sides of the cakes by suitable means in the pressing, or subsequently cut or drilled in them. The object of these channels is stated to be for the spread.

of the flame equally and rapidly in all directions, over and between the surfaces of the cakes as well as through the perforations in them, so that the whole cake and the whole of the charge may be ignited with great rapidity and burnt with great uniformity. The objects, it may be noted, differ from those aimed at in the Rodman perforated cake. The central hole should bear some relation to the proposed diameter and the length of the cartridge; the disks may be of any required thickness, from one-half inch to six or more inches, and any number may be employed to form a cartridge or charge, the central holes being kept in the centre of the cartridge, and the other holes corresponding to each other.

The disks may be of the same diameter as the powder chamber of the gun or they may be smaller, and the annular space may be filled with any other description of powder.

One of the specifications claims the use of the solution of gun-cotton, or of celluloid or similar material, as a cement or waterproof coating for the individual cakes forming a cartridge; and in the (1888) specification, instead of disks, he proposes the compressing of gun-powder or other explosives in the form of segments of a circle (they appear from the drawing to be sectors of a circle), so that when placed together they form rings or disks of a diameter suitable to the powder chamber of the gun. The segments are provided with projections and recesses to lock the segments of the cakes and the individual cakes one to another, so as to prevent any twisting or sliding movement; the junctions of the segments being so disposed that the segments "break joint" with respect one to another, the whole thus forming a rigid cylindrical cartridge or charge.

**Noble's Powder.**—In 1886, Colonel W. H. Noble proposed to build up cylindrical charges for guns, practically in the same manner patented by Mr. Quick two years later. Colonel Noble also claims improvements in the preparation of charcoal for gun-powder, with a view of obtaining charcoal of uniform chemical composition. In charring wood, he proposes to previously crush it, to char some of it rapidly and some slowly, so as to produce charcoals containing different percentages of carbon to be ascertained by analysis, and to make a blend of the charcoals in such



proportion as to furnish a charcoal containing the desired amount of carbon. He also proposes to employ uncharred turf or bog-stuff (previously washed, dried and ground) either alone or mixed with charcoal.

The subject of smokeless powders, (except those having ammonium nitrate for the base) at least such as have as yet appeared, belongs properly to the class of explosive compounds, and will be considered subsequently.

## LECTURE VII.

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### GUNPOWDER—CONTINUED.

**Properties of Gunpowder.**—Good gunpowder should be composed of hard angular grains which do not soil the fingers, and should have a perfectly uniform dark grey color. When new, it should be free from dust and a gramme of it flashed on a copper or porcelain plate should leave no residue or foulness. It should give the required initial velocity to the projectile, and produce not more than the maximum strain upon the gun. When exposed to air of average dryness, it should not absorb more than from 0.5 to 1.5 per cent. of water. In damp air gunpowder absorbs a much larger proportion of water, and deteriorates in consequence of the saltpetre being dissolved and crystallizing on the surface of the grains, while actual contact with water dissolves the saltpetre entirely and disintegrates the grains.

The property which exercises the greatest influence upon the general character of gunpowder, and the phenomena which attend its application as a propelling agent is its *density*—*absolute density* or *specific gravity*. By density is meant the ratio which the weight of a given volume of the powder bears to the weight of an equal volume of water at 15°.5 C. It varies from about 1.50 to 1.85. On account of its importance, it would be well to consider this quality of gunpowder more closely. Density must not be confounded with hardness. A substance may be very hard and yet be of a low density. A powder with a very hard surface may be in reality less dense than another, the surface of which is softer. Of course a very high density cannot be communicated without producing a considerable degree of hardness; but a powder may be made hard without rendering it very dense. Hardness seems to bear a direct relation to the power exerted in compressing, while density does not. Powder dust containing about six per cent. of moisture can be made very dense by the application of

moderate pressure, while that containing one per cent. can be brought to the same degree of density only by the exertion of enormous force; of these powders, the latter will be the harder.

Assuming the usual values assigned to the elements of gun-powder in the scale of specific gravities, the absolute density of a homogeneous mass of the mixture is 1.985. It is needless to say that this point is never reached in practical manufacture.

By subjecting powder-meal to powerful pressure its density is greatly increased, and consequently a given bulk of the pressed powder will yield on combustion a much greater volume of gas than an equal bulk of mill-cake. It becomes obvious then that the density of the powder which can be varied at will, becomes its *most important* physical quality, on account of the great influence which it exerts on its action when ignited. It is evident that, if different amounts of material be compressed into equal bulks, the effect of equal amounts of the resulting powder, whether by weight or volume, will not be equal. No experimental proof is necessary to show that if two grammes of powder of equal size, one of which is twice as dense as the other, be ignited in the open air, the denser will take a longer time to burn; for the former not only has a closer and less porous texture of grain, but contains a larger quantity of matter, bulk for bulk, to be burned from nearly the same surface, for in this case combustion occurs under the normal atmospheric pressure.

Under similar circumstances and conditions, differences in density may be assumed to effect the following changes in the manner in which a gramme of powder, of average mammoth size is consumed in a gun:

*First.*—On ignition it takes fire all over the surface, when, if sufficiently dense, it continues burning toward the centre in concentric layers until it is entirely consumed.

*Second.*—If of too low density to resist the pressure to which it is exposed in the gun, the heated gases at once penetrate the pores, lighting their walls as they advance, thus causing a development of gas from a surface many times greater than that which may be called the original external surface.

It is therefore evident that uniformity of results and effect cannot be obtained in fired gunpowder, unless the density be uniform and constant from one discharge to another.

**Tests for Gunpowder.**—From what has been said, it is evident that certain defined physical and mechanical properties are essential in order that a uniform standard of results may be maintained, and that it is necessary that these points be determined with extreme accuracy and precision in the case of all military powders. The most important determinations to be made are:

1. The purity and proportions of the ingredients.
2. The hygroscopic quality of the mixture.
3. The thoroughness of incorporation.
4. The granulation and hardness.
5. The absolute density or specific gravity.
6. The gravimetric density.

**Analysis of Gunpowder.**—A complete analysis of gunpowder includes the estimation of the ingredients, the determination of the nature of the charcoal, and the degree of purity of the ingredients. When powder has been damaged by moisture or otherwise, or when a powder of new or unknown manufacture is to be examined, it should be tested qualitatively for various impurities suggested by the particular cases under consideration, and the method of qualitative analysis to be adopted is determined by the results. A powder of known manufacture is examined qualitatively to determine the essential constituents, and the chlorides and moisture. The following is the most reliable process. The determination of the nitre depends upon its solubility in water, while charcoal and sulphur are insoluble. That of sulphur depends upon its easy oxidation by means of fuming nitric acid and potassium chlorate, forming sulphates, which are estimated by precipitation as barium sulphate.

Three samples of gunpowder are weighed in rapid succession (in order that the percentage of moisture determined for one shall be true for all) in the following manner:

Two watch-glasses of equal size, with a clamp to fasten them together, are dried and weighed. A sample of powder (5 grammes) is then introduced and the whole reweighed, the difference is the weight of powder used. This sample (N) is placed in a beaker, of about 150 c. c. capacity, for the determination of the nitre. Another sample of powder of the same weight is introduced into the watch-glasses and weighed as before. This sample (S) is placed in a tall narrow beaker, of about 300 c. c. capacity, for the determination of the sulphur. A third sample of the same weight is introduced into the watch-glasses and weighed as before.

This sample (M) is placed, together with the watch-glasses and clamp, in a drying oven, and dried at not exceeding  $60^{\circ}$  C., for about 24 hours. It is then removed from the oven, the glasses are clamped, and the whole placed in the scale case to cool. It is then reweighed. The loss of weight determines the *moisture*.

Sample N is covered with water (about 50 c. c.) heated to  $100^{\circ}$  C., and allowed to settle. Meanwhile, two filters of the same size are prepared, and their difference in weight is determined. These are to form a double filter, the lighter being always placed underneath for convenience. A wide beaker, of about 300 c. c. capacity, is also weighed. The clear portion of the solution is decanted on the double filter, and the filtrate received in the weighed beaker. The residue is again treated with boiling water and the operation repeated. The residue is then washed from the beaker upon the filter, by means of boiling water, being careful that every particle of residue is rinsed out of the beaker. The filtrate is evaporated to dryness in a water-bath, heated to  $148^{\circ}$  C. in an air bath, and weighed. The increase of weight determines the *nitre directly*.

The residue is dried on the filter at  $60^{\circ}$  C. and weighed on the upper filter, balancing this filter by means of the lower. The loss of weight, minus the difference in weight of the two filters, and corrected for moisture, determines the *nitre by difference*.

Sample S is covered with about 50 c. c. of fuming nitric acid, chemically pure, and brought to and maintained at a gentle ebullition. Small quantities of very finely pulverized potassium chlorate are added with caution, so that the liquid will not foam

over, until a clear solution is obtained, being careful to add no more chlorate than is necessary for this purpose. If at any time there is a tendency to foam over, the beaker should be at once removed from the heat and allowed to cool. The solution is allowed to cool and hydrochloric acid is added in small quantities at first from a pipette, then as the action decreases it is poured in, until the amount of liquid in the beaker is about doubled. The whole is evaporated to dryness, redissolved in about 50 c. c. of water, made up to exactly 100 c. c., which is usually a sufficient and convenient quantity, filtered, and the amount of sulphur ascertained by means of a decinormal solution of barium chloride. A normal solution is prepared by dissolving 244 grammes of the crystallized salt,  $\text{Ba Cl}_2 \cdot 2 \text{H}_2 \text{O}$ , in 1 litre of water; the decinormal solution is prepared by diluting a portion of this to ten times its volume.

To determine the sulphur, 5 c. c. of the solution containing the sulphates is put into a test tube and a portion of the decinormal solution of barium chloride is added from a burette and the tube well shaken; when the precipitate has settled, a drop or two more is added, and if cloudiness is produced more is added until the addition of a drop of barium chloride no longer produces cloudiness. Having thus approximately determined the amount of barium chloride required to precipitate the sulphates, a series of solutions, of 5 c. c. of the solution of sulphates containing greater and less amounts of barium chloride is prepared. Thus, if 7.2 c. c. was found to be the approximate amount required, the series would contain 6.8, 7.0, 7.2, 7.4, 7.6, 7.8 c. c. The precipitates are allowed to settle and the tubes are tapped with the finger until the bubbles at the top disappear. A few drops of the solution of barium chloride are then poured in separate drops on a clean violet or ruby colored glass plate, and a few drops of the solution of sulphates on another portion of the plate. A drop of one of the clear solutions in the test tubes, beginning usually with the lowest, is then put on the plate near one of each of the two solutions on the plate. One of the two drops thus placed is let into the drop of the solution of sulphates, the other into the drop of the solution of barium chloride, by means of a clean glass rod. If cloudiness appears in the sulphate solution take the next

higher (to which more barium chloride has been added), and so on; if cloudiness appears in the solution of sulphates, take the next lower (to which less barium chloride has been added), and so on, until a point is reached where no cloudiness is produced in either solution.

In making an analysis of U. S. regulation powders, the percentage of sulphur in the mixture being fixed as far as possible, the following method may be substituted for that just described, which, in practice, will be found to require very delicate manipulation. The amount of sulphur in these powders may be assumed to be 10 per cent., which for the amount under analysis (5 grammes) will be 0.5 gramme or 500 milligrammes.

From the reaction  $M_2 SO_4 + Ba Cl_2 = Ba SO_4 + 2 M Cl$ , it is evident that every molecule of barium chloride detects one atom of sulphur; hence, every cubic centimetre of normal solution of barium chloride (since it contains a number of milligrammes of barium chloride equal to its molecular weight) is equivalent to a number of milligrammes of sulphur equal to its atomic weight, or 32. Every c. c. of a decinormal solution will then be equivalent to  $\frac{32}{10}$  mg. sulphur. There were 100 c. c. of the solution of sulphates, 5 of which were used in the determination; hence,  $\frac{32}{10} \times 20 \times$  the number of c. c. of barium chloride solution used, determines the weight of the *sulphur* in milligrammes.

To determine then the several amounts of  $Ba Cl_2$  to be added to each test tube in order to form the first approximate series, we may substitute in the last expression

$$\frac{32}{10} \times 20 \times x = 500, \text{ or } x = 7.8.$$

Hence, we may now make our first approximation by adding to the six tubes in succession 7.4, 7.6, 7.8, 8.0, 8.2 and 8.4 c. c. respectively. They are then placed in a test tube holder and the precipitates allowed to settle. A few drops of the  $Ba Cl_2$  solution are then introduced into each tube by means of a pipette until two consecutive tubes are found, in one of which an additional precipitate of  $Ba SO_4$  is formed, while the other remains perfectly clear.

The result of this operation which consumes but a few minutes, enables us to form a second series of solutions of 5 c. c. each, in which the approximation is so close that the result may be accepted as practically exact. Suppose that as a result of the first approximation, the two consecutive tubes were those in which 7.8 and 8.0 c. c. of the  $\text{Ba Cl}_2$  solution had been added. We then proceed to form a second series of solutions by adding 7.7, 7.8, 7.9, 8.0, 8.1 and 8.2 c. c. of the  $\text{Ba Cl}_2$  solution to the several tubes in succession. Allow the precipitates to settle and proceed as before. In this way the degree of approximation is very close, while in practice, it has been found much easier to detect the exact point at which all of the  $\text{Ba SO}_4$  has been precipitated, than in the manner previously described.

The charcoal is determined (a) by ascertaining the percentage of nitre and sulphur in one sample of gunpowder and subtracting their sum from 100; or (b) by extracting the nitre from one sample and subtracting from the weight of the residue that of the sulphur found in an equal weight of another sample.

The chlorides are determined by redissolving the nitre obtained in the estimation of nitre by the direct method in the smallest quantity of water, and proceeding as in the estimation of chlorides explained under Nitre.

The following example will illustrate the method of analysis just described and the form of record:

## DEPARTMENT OF CHEMISTRY AND EXPLOSIVES,

### ANALYSIS OF GUNPOWDER.

Fort Monroe, Va., April 22nd, 1889.

*Kind of Powder:* Hexagonal, E. V. D. (DuPont)

	Milligrammes.
Weight of watch crystals + clamp	19804
Weight of watch crystals clamp + powder	24804
Weight of watch crystals clamp powder dry	24745
Moisture	59



Percentage of <i>moisture</i> , $5000 : 59 :: 100 : x =$	1.18 per cent.
Weight of powder corrected for moisture	4941
Weight of beaker + nitre	86961
Weight of beaker	83300
Weight of nitre— <i>direct</i>	3661
Percentage of <i>nitre (direct)</i> ,	
$4941 : 3661 :: 100 : x =$	74.094 per cent.
Difference in weight of filters + residue	1334
Difference in weight of filters	50
Weight of residue <sup>(1)</sup>	1284
Weight of <i>nitre—by difference</i> (4941—1284)	3657
Percentage of <i>nitre (by difference)</i> ,	
$4941 : 3657 :: 100 : x =$	74.013 per cent.
Weight of powder corrected for moisture	4941
Sulphate solution measures 110 c. c.	
Amount tested 5 c. c. required $7.7 \text{ c. c. } \frac{A}{10} \text{ Ba Cl}_2$	
Weight of sulphur <sup>(2)</sup> $7.7 \times 0.0032 \times 22 =$	542
Percentage of <i>sulphur</i> $4941 : 542 :: 100 : x =$	10.971 per cent.
Weight of residue <sup>(1)</sup>	1284
Weight of sulphur <sup>(2)</sup>	542
Weight of charcoal	742
Percentage of <i>charcoal</i> $4941 : 742 :: 100 : x =$	15.015 per cent.
Percentage of nitre (direct)	74.094 (by diff.) 74.013
Percentage of sulphur	10.971 10.971
Percentage of charcoal (a)	14.945 (b) 15.015
	<hr/>
	100.000 99.999

#### Determination of the Hygroscopic Quality of the Powder.—

The amount and percentage of moisture in the powder is determined as has just been described in the analysis of gunpowder. The ability to resist moisture is determined by subjecting samples of the powder, which have been dried, to exposure, first, in the open air; second, in the hygroscope containing a solution of salt-petre made at  $100^\circ$  and cooled down to  $80^\circ \text{ F}$ .

The hygroscope is an air tight box arranged to contain specimens of powder, while subjecting them to a damp atmosphere at nearly uniform temperatures for 24 hours. It consists of two

parts, an inner compartment of copper (about 12" x 12") and the outer case of wood, the two being separated by a space of two inches which is solidly packed with hair. The top or lid is also double and made non-conducting by hair packing, the lower face being of copper and fitting closely to the sides of the inner compartment. As an additional precaution, an india rubber gasket extends around the top of the outer case, and the top is drawn into very close contact with this by means of thumb screws. A movable tray of copper, the bottom of which is perforated, rests upon projections from the walls of the inner compartment.

The powder to be tested is placed in circular cups, one inch in depth and three inches in diameter, which are fitted with wire gauze bottoms of sufficiently small mesh to contain the finest grained powder. The percentage of gain is determined by weighing in carefully prepared bottles, into which the powder is introduced as soon as the hygroscope is opened.

The influence of atmospheric conditions on the quantity of moisture absorbed by the powder is so great, that accuracy requires that a careful record be kept of the barometer, hygrometer, external thermometer, and of a maximum and minimum thermometer, fitted inside of the hygroscope whenever samples are being tested, and in each case reference should be made to tables previously worked out in the case of a standard powder of like specific gravity, and granulation under like conditions.

**Test for proper incorporation.**—Thoroughly incorporated powder presents a perfectly homogeneous appearance, and upon breaking up a granule it should show an ashen grey color, and the texture should be very close; a granular appearance, and especially the presence of any white specks is inadmissible. This examination should be made with the assistance of a magnifying glass.

The flashing of a gramme or so of the powder on a copper or porcelain plate has been alluded to, but to form an accurate judgment, and especially to compare the degrees of incorporation of different powders by this test requires great care and experience. As an improvement upon this rather crude test, Colonel Chabrier proposed what he termed a "Pyrographic Method for

the Examination of Gunpowder." This method consists in flashing the powder on sheets of paper colored blue with iodide of starch, the result being a bleaching of the paper in spots and streaks. From the size, shape and general appearance and arrangement of the spots and streaks, the character of the powder is determined.

This process is an advance upon the original one, but practically considerable difficulty was encountered in the preparation of the paper before use, and the preservation of the record thereon after the test had been applied.

The following method of applying the "Flashing Test" has been proposed by Professor Munroe, of the U. S. Naval Torpedo Station, and has given excellent results.

Instead of the iodide of starch paper, he employs a paper colored with Turnbull's Blue, which is decomposed (and its color thereby destroyed) by solutions of the alkalies and the alkaline carbonates. The alkaline sulphides and thiosulphates also act upon this paper with the partial production of a yellow color, therefore, by flashing gunpowder upon such paper, yellow and white spots will be formed. The test is made as follows:

Pieces of the paper, 6 or 8 inches square, are dampened and placed on a glass or porcelain plate. A small truncated leaden cone (3 grammes in capacity) is closed at the smaller end with the finger and filled evenly with the powder to be tested. The powder is placed upon the paper by inverting the cone carefully so as to produce a conical heap which is immediately fired, either by a heated iron or copper wire, or better still, by a fine platinum wire heated to incandescence by an electric current. The paper is exposed to the action of the residue for 30 seconds, and then washed in running water.

When pulverized mill-cake is flashed in this way, the space described by the base of the cone will be blackened and partially bleached by the dampened layers of powder in contact with it; next above this space will be black smutches and streaks, while the whole surface of the paper will be covered with white and yellow spots. With badly incorporated powders, these spots are coarse and irregular in shape and distribution; while in the case

of thoroughly incorporated powders, the spots are fine and so evenly distributed over the surface of the paper, that it appears merely of a paler color with occasional spots and streaks.

**Granulation and Hardness.**—The size of the grain is determined by standard sieves made of sheet brass. Two sieves are used for each kind of powder, and the diameters of the holes are as follows:

KIND OF POWDER.	No.	DIAMETER.	No.	DIAMETER.
Musket,	1	0.''03	2	0.''06
Mortar,	3	0.''10	4	0.''25
Cannon,	5	0.''25	6	0.''50
Mammoth,	7	0.''75	8	0.''90

The dimensions of the special powders have been given elsewhere. The shape of the grains can be judged only by the eye, but the more recent powders belong to the class known as Powders of Regular Granulation and are very uniform in shape; however a compact shape approaching a cube or sphere is preferable, and elongated flat scales are very undesirable. The hardness can be determined only approximately, since the hardest grained powder is considerably below any scale used for determining this quality. Experience in this matter is the only guide, and it is a very difficult thing to determine the relative hardness of the various powders.

On account of the importance of the exact determination of the density of powder, I have decided to devote an entire lecture to that subject, and will merely add a few words of precaution as to the care of gunpowder:

**Preservation, Storage and Transportation of Gunpowder.**—

Before leaving the subject of gunpowder, it remains to add a few precautions as to its preservation, storage, and transportation. Government powder is packed in barrels of 100 pounds each. Powder barrels are made of well seasoned white oak and hooped with hickory or cedar hoops, which should be deprived of their bark. The hoops should cover two-thirds of the barrel. Instead

of a bung on one side a screw hole  $1\frac{1}{2}$  inches in diameter is made in the head of the barrel for mortar and musket powder; it is closed by a wood-screw with an octagonal head which must not project beyond the ends of the staves; under the head of the screw is a leather washer steeped in a solution of beeswax in turpentine. For transportation, a piece of cloth should be glued over the head of the screw. Powder barrels may be hooped with copper, and boxes lined with galvanized iron and copper with large screw lids have also been tried as substitutes for the ordinary barrel. The heads of each barrel are painted black, and on them are marked (in white oil paint) the number of the barrel, the name of the manufacturer, the year of fabrication, the kind of powder, the mean initial velocity, the pressure per square inch and the density.

In the powder magazines the barrels are generally placed on their sides, three tiers high, or four tiers if necessary. Small skids should be placed on the floor and between the several tiers of barrels in order to steady them, and chocks should be placed at intervals on the skids to prevent the rolling of the barrels. The powder should be separated according to its kind, the place and date of fabrication, and the proof range. Fixed ammunition, especially for cannon, should not be put in the same magazine with powder in barrels, if it can be avoided.

Fireworks should never be stored in powder magazines.

In a room 13 or 14 feet wide, the barrels may be arranged in a double row in the center, two alleys  $2\frac{1}{2}$  feet wide, and two single rows 6 to 12 inches from the walls; in this way the marks of each barrel may be seen and any barrel can be easily reached. In a room 12 feet wide, an equal number of barrels may be placed in two double rows, with a central alley of 3 feet, and two side alleys, next the walls of about 10 inches each. There should be an unencumbered space of 6 or 8 feet at the door or doors of the magazine.

Should it be necessary to pile the barrels more than four tiers high, the upper tiers should be supported by a frame resting on the floor; or the barrels may be placed on their heads with boards between the tiers.

Besides being recorded in the magazine book, each parcel of powder should be inscribed on a ticket attached to the pile, showing the entries and the issues.

For the preservation of the powder and of the floors and lining of the magazine, it is of the greatest importance to preserve unobstructed the circulation of air under the flooring as well as above. The magazine should be opened and aired in clear dry weather, *when the temperature of the air outside is lower than that inside the magazine.* It should not be opened in damp weather if it can be avoided. The ventilators must be kept free; no shrubbery or trees should be allowed to grow so near as to protect the building from the sun. The magazine yard should be paved and well drained. The moisture of a magazine may be absorbed by chloride of calcium suspended in an open box under the arch, and renewed from time to time; quicklime is dangerous and should not be used.

The sentinel or guard at a magazine, when it is open, should have no fire-arms, and every one who enters the magazine should take off his shoes, or put socks over them; no sword or cane, or anything which might occasion sparks should be carried in.

The windows should have inside shutters of copper wire-cloth. Fire should never be kindled near the magazine for the repair of the roof or lightning rods.

Barrels of powder should not be rolled for transportation; they should be carried in hand-barrows, or slings made of rope or leather. In moving powder in the magazine a cloth or carpet should be spread; all instruments used there should be of wood or copper, and the barrels should never be repaired in the magazine. When it is necessary to roll the powder for its better preservation and to prevent its caking, this should be done, with a small quantity at a time, on boards in the magazine yard.

In the spring an inspection of the barrels should be made, and the hoops swept with a brush wherever they can be got at, to remove the insects which deposit their eggs at this season.

In wagons, barrels of powder must be packed in straw, secured in such a manner as not to rub against each other, and the load covered with thick canvas.

In transportation by railroad, each barrel should be carefully boxed and packed, so as to avoid all friction. The barrels should have a thick paulin under them. The cars should have springs similar to those of passenger cars.

## LECTURE VIII.

### DENSIMETRY.

**Densimetry.**—The determination of the exact density of gun-powder is the object of *densimetry*. There are two densimeters in use at the Artillery School, one for the determination of the densities of mortar and cannon powders, and the other for use with the larger grained powders.

**The Mallet Densimeter.**—The apparatus used for the smaller grained powder, was invented by Colonel Mallet of the French Army. It consists of a small table to one end of which is firmly secured an iron standard, to which is attached a barometer tube of peculiar make; instead of being of a single piece and closed at the upper end, it is made of two separate pieces and open at the top. The upper part is about 24 inches in length and is connected to the lower which is 10 inches in length by means of a closely fitting and perfectly air-tight screwed metal joint; the lower part instead of being a plain parallel tube of the same diameter throughout as the upper, is made in the form of a globe or bulb (*vase*). To each end of this globe is attached a metal collar fitted with female screw threads, and the connections between the barometer tube above and the nozzle below are by metal plugs accurately fitted to these threads. The upper plug is fitted with a fine gauze diaphragm, which prevents grains or particles of powder from entering the upper part of the tube, while the lower plug is similarly fitted with a diaphragm of chamois skin, which strains and cleans the mercury before it enters the globe. The nozzle mentioned above screws into the lower plug and dips into the mercury. The lower extremity of the upper part of the tube and both plugs are fitted with air-tight stop-cocks.

The mercury is contained in a heavy porcelain dish which can be raised or lowered by means of a hand screw, so as to keep the tip of the nozzle immersed to the proper depth. The upper part



of the tube is attached to a scale, which in turn is attached to the standard. To the opposite end of the table is attached an air-pump of ordinary construction. The vacuum gauge is in an air tight glass case, which is placed between the standards on which the brake works; it can be shut off from connection with the cylinder by a stop-cock, and air is admitted to it and thence to the cylinder, etc., by unscrewing the glass cover, which can be turned by means of a chamfered ring on the brass collar into which it fits.

Connection with the *densimeter* is controlled by a stop-cock under the bell-glass table. The cylinder (of brass) oscillates on on trunnions at its base; its connections with the vacuum gauge and the *densimeter* are by means of rubber hose. The cylinder head is fitted with an oil hole closed by a screw plug, and has an overflow can to catch the oil forced out in exhausting. To prevent any mercury which might find its way from the top of the barometer tube from flowing into the air-pump, the densimeter and air-pump are connected by hose through the medium of a "catch bottle," into which the escaping mercury may overflow without damage.

The *balance* employed in connection with the densimeter is a beam-scale constructed with great accuracy. It consists of a beam of brass mounted on a hollow standard with ordinary scale-pans. The beam and scale-pans are supported on steel knife edges. The beam, when not in use, rests upon the top of the standard, the weight of the scale-pans being taken from their knife-edges by the base of support of the standard. The central knife-edge, when the beam is not in action, rests in V's in the head of the standard, but bears no weight. The beam is thrown in and out of action by means of a lever at the foot of the standard, which acts on a stout rod running up through the standard. To the upper extremity of this rod is attached a double cross-head, the upper surfaces of which are faced with polished hardened steel, and on these surfaces the pivoting or central knife edge rests in weighing. A pointer extends from the beam downwards, and the oscillations are marked by a scale attached to the foot of the

standard. To the base of support is attached a German level, and the base itself is furnished with levelling screws, by means of which the apparatus may be levelled.

**Precautions to be observed in using the densimeter.—**

1. As all of the different connections of the globe where air-tight joints are made, are fitted with leather washers of constantly changing thickness, it follows that a variable degree of screwing up is required in order to make the junctions absolutely perfect. With the plugs which screw into the ends of the globe, it is of great importance that the extent to which they enter should be uniform for any given number of trials with the same powder; that is, they should be run in to the same distance when each sample of powder is tried, that they were when the globe was filled with mercury alone, for if not in far enough the capacity of the globe is increased, and if in too far it is reduced.

In order to eliminate this source of error as far as possible, set-marks are put on the collars and plugs. So long as these are either brought together or kept separated by a fixed and constant amount during the different trials, the experiment will be accurate. As coincidence will probably only occur when the washers are new, the separation as they wear away or become compressed must be determined for the several trials from which the determination of the density of any given sample of powder is to be calculated, and retained throughout those trials.

2. In screwing on the nozzle and in screwing in the plugs, both wrenches should be used—one as a spanner, to hold against the other used as a wrench, otherwise the cementing of the collars may be started and leaks produced. Attached to the table of the densimeter used at the Artillery School is a seat so arranged with projecting studs, that the globe may be placed therein and firmly held by the collars while the plugs and nozzle are being attached to or detached from the globe, so that all wrenching or twisting is removed from the cemented joints between the globe and collars.

3. The zero of the scale attached to the upper part of the barometer tube is *the lower end of the nozzle*. The quantity of mercury in the dish and the level on which the dish rests should be so regulated, that the immersion of the nozzle will not be greater when the globe is full than is necessary to prevent the admission of air. This is necessary in order to avoid fluctuations in the height of the barometric column, which are misleading as to the condition of the instrument.

4. When leaks in the connections of the globe occur they are indicated by air-bubbles, which can be distinctly seen passing up through the enclosed mercury. They can generally be located if about the junctions by closing the cocks in succession, beginning at the lowest and exhausting at the same time by means of the air-pump. If the leak be about the tube connections, the air will continue to flow with all the cocks closed; if it be below this point it can be located between the cocks. By tightening the junctions with the wrenches, or, if in the cocks, by screwing them up with a screw-driver the difficulty is remedied.

It sometimes happens that the cement which holds the collar to the neck of the globe becomes cracked and produces a leak; this can be located by filling the globe, closing both cocks, and expanding the mercury by wrapping a warm cloth around the globe; globules of mercury will be forced out at the point where the leak exists. By exhausting the globe and at the same time applying to the leak semi-melted beeswax, or a mixture of beeswax and tallow, the leak can be stopped.

5. When the globe is detached after it has been filled, every particle of mercury adhering to the plugs must be carefully removed by jarring or brushing. This precaution is very important. The mercury that thus adheres at different trials varies, therefore the accuracy of the weight taken is sensibly affected if care is not taken to remove all traces of mercury outside of the cocks. For the same reason any globules of mercury adhering to the globe and its connections should be removed by brushing before weighing. In testing fine grained powder, both plugs should be unscrewed, and, with the globe, carefully wiped out after each trial; with ordinary cannon powder this need be done only occasionally.

6. Whenever the upper part of the barometer tube or globe becomes coated with sulphuret of mercury, it should be dismounted and washed with *aqua regia*. Should the upper part of the barometer tube be broken, expose the metallic socket which holds the lower end, to the flame of a lamp until the cement softens, remove the broken tube and replace the socket. Coat the end of the new tube with cement, and insert it in the socket before the mixture cools, being careful that the tube stands vertical and attach it to the scale.

7. The following precautions are necessary in using the air-pump: Always keep the piston-rod and piston well oiled; keep the stop-cocks and connections air-tight; screw down the vacuum gauge before beginning to exhaust; examine the hose connections from time to time. To determine whether the pump is tight and in working order, close the cock under the bell glass table and exhaust. The vacuum gauge will show whether air is admitted, and the leak may be located by the hissing sound made by the air rushing in.

8. The following precautions are to be observed in using the balance: Always lower the beam before putting the globe or the estimated counterbalancing weights on the pans, and also before removing either of them. The small weights may be added or changed with the beam in action. Always place the heavier weights in the center of the pans so as to avoid any tendency to swing the beam laterally. In throwing the beam into action, use a gentle regular motion. The oscillations when the balance is nearly in equilibrium, may be checked by gently lowering the beam and pans into their rests until the motion ceases. When again raised, the beam will be quite steady, and exact equilibrium will be easily established.

**The process of determining the density of a sample of powder.**—The connections of the instrument having been previously tested and everything found in working order, the globe, with the nozzle attached, is carefully brushed and connected to the upper part of the barometer tube. The bowl containing the mercury is raised by means of the elevating screw, until the tip of the

nozzle is immersed to a sufficient depth to prevent any air getting into the globe. The lower stop-cock is closed, all the others are opened and the air is exhausted from the globe and tube by means of the air-pump. As soon as a perfect (or nearly perfect) vacuum is obtained, as shown by the vacuum gauge, the lower stop-cock is opened.

The mercury immediately rises into the globe, and, as the level of the mercury in the bowl falls, great care must be taken to keep the tip of the nozzle constantly immersed to a uniform depth by means of the elevating screw. As soon as the column of mercury becomes stationary (it should rise in an unbroken column to about the usual barometric height), the lower stop-cock is closed. Air is then admitted to the top of the tube by opening the stop-cock attached to the catch bottle, which will cause a very slight fall in the mercury column. The other stop-cocks of the globe and tube are then closed, the globe carefully disconnected, placed in its seat on the table, the nozzle removed, and all traces of adhering mercury jarred and brushed off. The globe filled with mercury is then very carefully weighed and the weight noted (W). The globe is next emptied, the mercury being returned to the bowl and the upper plug of the globe removed, so that the sample of the powder can be introduced.

For many practical reasons it has been found convenient to use a constant, uniform weight of powder, the weight adopted at this school being 9 *ounces*, or 3937.5 *grains*. The sample carefully weighed is introduced into the globe, the nozzle attached, and the globe again connected with the rest of the instrument. The cock at the lower end of the upper part of the tube is opened to allow the mercury remaining in it to escape, the catch bottle and nozzle stop-cocks closed, and the air is again exhausted.

The mercury is run into the globe and up to the same point in the tube as before, the cock closed, air admitted, and globe disconnected, cleaned and weighed as before. This weight (W') is also noted. As during the experiment the temperature of the mercury has varied (due to the rapid manipulation, its temperature should be determined at the beginning of the experiment and after each weighing, and the mean of the three thermometric readings taken as the true temperature, corresponding to

which the specific gravity of the mercury is to be taken in the subsequent calculation. From the data thus obtained, the density of the powder is readily obtained from the proportion.

$$D : d :: W - (W' - w) : w,$$

or

$$d = \frac{D \times w}{W - (W' - w)}, \text{ in which}$$

D = the density of the mercury corresponding to the temperature noted.

d = the density of the powder to be determined.

W = the weight of the globe filled with mercury alone.

W' = the weight of the globe filled with mercury and powder.

w = the weight of the sample of powder taken.

Evidently  $W - w$  represents the weight of mercury, globe, and powder less the weight of powder taken, and  $W - (W' - w)$ , the weight of mercury displaced by the powder.

It is very important in these experiments that the mercury should be of the proper quality, and in addition to straining it through chamois skin from time to time to remove any impurities, its specific gravity should be tested. At 66° F, or 18°.9 C, it should have a Sp. Gr. of 13.55055.

**The Dupont Densimeter.**—For the determination of the density of large-grained powders, the instrument in use at the Artillery School was constructed according to the plan of one designed by the Dupont Powder Company, and employed by them with very satisfactory results at their works near Wilmington, Del.

It is a mercury densimeter, adapted, by its construction, to the reception of large grains, and having capacity for five pounds of powder, which for convenience, is the weight of sample always employed. It differs, however, from the small densimeter just described by a combination of the different parts, such that the reservoir for holding the powder and mercury to be weighed, and the balance, by means of which the weighings are made, are assembled together in one instrument: The balance also is so adapted to its special purpose as to simplify considerably the subsequent process of calculation.

A great saving of time and labor is gained by this form of instrument, and the occurrence of breaks and leaks, so frequent in the small apparatus, is in a great measure avoided.

The instrument is enclosed in a case about seven feet long by two feet wide and six feet high, built upon a solid brick support, access to the instrument being had through double doors which, when open, expose one entire side.

The instrument consists essentially of three parts, viz: a beam-scale, a reservoir to contain the powder and mercury to be weighed, and a bowl to contain the mercury when not required in the reservoir.

The *beam-scale* is suspended from a hook firmly secured to the top of the case, and its axis of suspension is a knife-edge lying in the same plane with the axis of suspension of the reservoir and of the rods to which are attached the platforms on which the weights are placed. The latter consists of pounds, tenths of a pound, and five-hundredths of a pound, *marked with reference to the weights they will balance in the reservoir*; and of a large unmarked weight, termed the *counterpoise*.

This counterpoise has a cavity bored in it lengthwise, the use of which will appear hereafter; its weight is about eight pounds. The long arm of the beam is also graduated, and by means of a "rider", the weighings can be made to hundredths and thousandths of a pound; the graduated edge of the beam is in the same plane with the knife-edges. Attached to the upper edge of the beam are two small counterpoises which admit of movements parallel and perpendicular to the beam respectively, the movements being regulated by screw spindles passing through the counterpoises. The one having the parallel or horizontal motion is just over the axis of suspension of the beam, and is used to adjust the arms to the same weight; the other having the perpendicular or vertical motion is attached to the shorter arm, and its function is to regulate the sensibility of the balance. The beam and its appurtenances are of brass.

The *reservoir* is of cast-iron, and consists of two conical ends, which screw into a cylindrical section. These joints are fitted most accurately lest ledges should be formed within the reservoir, which might serve to retain enough mercury to affect the weigh-

ings. Attached to the top of the reservoir is a small detachable glass vase into which the mercury rises when the reservoir is filled, and which enables the operator to mark the exact point to which it must be filled for any given experiment. A nozzle, fitted with an air-tight stop-cock, screws into the lower conical section.

The reservoir swings on trunnions, the beds for which are at the lower extremities of a yoke attached to the beam. The upper part of the yoke is fitted with a vertical pivot, by means of which, in addition to a vertical or up-and-down motion, the reservoir may be given a horizontal angular movement.

The powder is introduced into the reservoir through a circular mouth about  $2\frac{1}{2}$  inches in diameter in the upper conical section.

A screw-cap, fitted with a soft leather washer, covers the mouth, and when removed, for the purpose of introducing the powder, is hung on a hook attached to the right-hand side of the yoke, so as to be included in the weighing. The mercury is admitted to the reservoir and withdrawn through the nozzle already mentioned.

The capacity of the reservoir is about 78 pounds of mercury alone, or 40 pounds of mercury and 5 pounds of powder. The reservoir itself weighs  $20\frac{1}{2}$  pounds.

The *bowl* is also of cast-iron, and has a capacity for about 110 pounds of mercury. By means of an elevating-screw, worked by a wheel, it can be raised or lowered so as to keep the tip of the nozzle always immersed at a uniform depth. Near the bottom of the bowl, and to one side, is an outlet pipe, by means of which the mercury can be withdrawn when the instrument is not in use.

In connection with this densimeter is used an ordinary Ritchie air-pump, in which the cylinder remaining stationary, the oscillation takes place in the connecting-rod, which communicates the motion of the handle to the piston. The air-pump and densimeter are connected through a catch-bottle by means of rubber hose.

**Precautions to be observed in using the Dupont Densimeter.**—After the instrument has once been put in thoroughly good working order, serious injury to it can result only from very rough treatment. However it is well to observe the following precautions:

1. In removing the reservoir from the yoke, disconnect the rubber hose from the glass vase, revolve the reservoir on its trun-



nions until it is inclined about  $30^{\circ}$  from the vertical, and then raise it obliquely and *very gently*, so as to avoid any jar or shock upon the knife-edges of the beam. To replace it, be equally careful.

2. When removed in order to brush the globules of mercury, place the reservoir on a table so that it rests on its sides, and, having taken off the screw-cap, brush out the interior carefully, inverting the reservoir to allow the mercury to run out. A slight jar will free the nozzle from any particles of adhering mercury. Always examine the screw-threads on the cap, as a few globules of mercury always find their way into them.

3. The joint between the glass vase and the metal top of the reservoir is very delicate and difficult to keep perfectly air-tight. Therefore be particularly careful not to strike the vase, or jar it in any manner, especially in removing or replacing the rubber hose. The latter should always be brought from the catch-bottle over the hook to which the beam is attached.

4. It is not necessary to use force to make the screw-cap joint air-tight, provided the leather washer is not worn out. The exercise of a very gentle pressure on the wrench is sufficient.

5. When running the mercury into the reservoir, keep the nozzle immersed at such a constant uniform depth as to prevent any air from getting into the instrument. As it will be found necessary to continue to exhaust the air until the mercury has risen to the proper level, care should be taken to work the brake with uniform strokes so that the flow of mercury may be regular.

6. The process of weighing is often a very important operation on account of the extreme sensibility of the beam-scale. As there is no way of arresting the vibrations except by the hand, when equilibrium is nearly produced, it is convenient to arrest the vibrations by holding the thumb and forefinger of the right hand a little below and above the support for weights attached to the longer (right) arm of the beam, while with the left hand, the "rider" is manipulated until equilibrium is produced.

7. The precautions necessary for the proper care of the air pump have already been enumerated. To preserve the reservoir

from rust while the instrument is not in use, it is covered with a light coat of paraffin, which can be readily removed by holding it over a flame.

**To determine the Density of Powder with the Dupont Densimeter.**—The reservoir having been carefully cleaned and placed in the yoke, the beam is accurately balanced by means of the counterpoise used for that purpose, and the eight pound counterpoise placed on the left-hand support. The bowl is then filled with mercury and run up by means of the elevating-screw until the tip of the nozzle is immersed to the proper depth. The densimeter is then connected with the air-pump, the nozzle stop-cock closed, and the air exhausted by the air-pump.

As soon as the gauge indicates a vacuum, the stop-cock is opened and the mercury rises in the reservoir, the air-pump, in the meantime, being worked constantly and uniformly. When the mercury column reaches the proper height in the vase, the stop-cock is closed, the hose disconnected, and the point at which the mercury stands marked by a wire used for the purpose. (When the hose is disconnected, it sometimes happens that the mercury column falls too low to be marked by the wire; in this case, a little mercury is poured into the tube from the top, and the point marked as before. Occasionally a little mercury has to be run off, which can be done by carefully opening the stop-cock until the mark is reached).

The balance of the beam is now restored by dropping small shot into the cavity of the counterpoise, the weight of the latter being slightly less than the reservoir when filled with mercury alone; this having been done, the stop-cock is opened and the reservoir emptied.

The reservoir is removed from the yoke, the cap-screw taken off, and all particles of mercury carefully brushed and *jarred* out; it is then replaced in the yoke, the cap hung on the hook, and the large counterpoise having been removed, the equilibrium of the beam is verified.

The five pound weight is now placed upon the left-hand support, and the sample of powder introduced into the reservoir until equilibrium is again restored.

The screw-cap is then replaced, the large counterpoise added to the five pound weight already on the left-hand support, and the reservoir filled with mercury, by means of the air-pump, to the same height as before. The rubber hose is again disconnected from the vase, and equilibrium for the fourth time restored by placing weights on the right-hand platform (attached to the longer arm of the beam), and, in addition, by manipulating the "rider" on the beam, if necessary. The sum of these weights is the weight of the mercury displaced by the powder, or of a volume of mercury equal to the volume of the powder, and the specific gravity, or *density*, of the latter results from the well established principle that "*the specific gravities of two substances are proportional to the weights of equal volumes of those substances*".

As the density of mercury varies with its temperature, and this temperature varies during each experiment, it is necessary to determine the temperature of the mercury at the beginning of the experiment and each time that the reservoir is emptied, and the mean of the thermometric readings taken as the temperature corresponding to which the specific gravity, or density, of the mercury is to be taken in the subsequent calculations.

Thus, if

D = the density of the mercury corresponding to the observed temperature;

d = the density of the powder to be determined;

W = the sum of the weights on the longer arm;

w = the weight of the powder.

Then according to the principle enunciated

$$D : d :: W : w, \quad \text{or}$$

$$d = D \frac{w}{W}$$

In this densimeter not only are the weighings rapidly and accurately made, but the actual weights required for the computation are obtained directly by a process peculiar to the balance.

*The weights for the longer arm are marked double their actual value in reference to the reservoir*, so that in computing the density of any sample of powder, it is only necessary to place the decimal point

in the value of  $D$  one place farther to the right, and divide by the value of  $W$ , *as indicated on the weights*, which is evidently the same thing as multiplying both terms of the fraction  $\frac{w}{W}$  by 2,  $w$  always being 5 pounds.

On account of the considerable bulk of the sample employed, and the comparatively large weights of powder and mercury that consequently enter into the formula, very close weighing with this instrument is not absolutely requisite. For instance, a variation of 46 grains in the actual value of  $w$  affects the resulting density of the sample by only two points in the third place of decimals. This feature is one of great practical utility as it enables us to dispense with very small weights, and to abridge considerably the operation of weighing.

**Gravimetric Density of Gunpowder.**—Owing to the terms in which it has been defined, very inaccurate and even erroneous ideas exist as to what is meant by *gravimetric density*.

In the Report of the Chief of Ordnance for 1879, it is defined as “the weight of a given measured quantity”, and to this is added “it is usually expressed by the weight of a cubic foot in ounces.”

Major Makinlay, of the Royal Artillery, gives a better idea of what is meant by gravimetric density, but unfortunately confounds it with the air-space of the powder chamber, of which it is approximately a measure. According to the Woolwich Text-book, “the gravimetric density of a charge of powder in the chamber of a gun is the ratio of its weight to the weight of that volume of water which would fill the space behind the projectile in the gun. It is the mean density of the grains of powder and of all the interstitial and other spaces.”

It has been further defined as “the weight of a standard volume of the powder, not pressed together except by its own weight”. (Ingalls). None of these definitions appear to me to be satisfactory.

It is hardly necessary to say that the gravimetric density of gunpowder is entirely distinct from its absolute density, or specific gravity; in fact it bears no relation thereto, as will become ap-

parent subsequently, when we shall find that, according to the "gravimetre", an unusually *dense* powder may be made to appear much lighter than a powder of very low specific gravity.

In its general acceptation, the word "density" suggest a comparison, and is almost universally represented by an abstract number, which is the result of a ratio. This is so well known that, except for the errors referred to, the statement would be considered superfluous. I can discover no good reason for discarding the idea, and would therefore define *gravimetric density as the ratio which the weight of the substance bears to the volume it occupies.*

As in the case of absolute density there must be a standard to which this ratio is referred. The standard originally adopted in this country, and which is still retained is the weight in ounces of one cubic foot of distilled water at the standard temperature (assumed to be 1000 ounces.)

Since the specifications furnished by the U. S. Ordnance Department for the supply of service powders are expressed in terms of this standard, for practical reasons it will be adopted in our work.

To determine the gravimetric density of any powder then, it is only necessary to fill the "gravimetre" (a copper measure having the capacity of one cubic foot) and weigh it.

Hence if we represent by

W' the weight in ounces of one cubic foot of the sample, and by D' the gravimetric density

$$1000 : W' :: 1 : D' = \frac{W'}{1000}$$

It is evident that the gravimetric density of the powder would be unity when one cubic foot of it weighed exactly 1000 ounces.

The question of gravimetric density of gunpowder is of great practical importance, since upon it depend largely the velocity, pressure and range.

As before stated, from the gravimetric density of a sample of powder, an approximately correct idea can be formed as to the volume of air space in a given charge. The air space is dependent upon the size and shape of the granules, and the amount

of settling and shaking to which the powder is subjected, therefore in determining the air space, the percentages are calculated for the powder, both loose and settled.

Knowing the specific gravity, or absolute density of the powder under examination, as determined by the densimeter, the air space is found as follows:

Let  $D$  represent the absolute density of the powder

$D'$  the gravimetric density determined as above.

Then  $\frac{D'}{D}$  will be the fractional part, or per cent. of the cubic foot occupied by the powder, and

$1 - \frac{D'}{D}$  the fractional part, or per cent. of the cubic foot occupied by the air, or the *air space in that volume*.

**The Dupont Gravimetric Balance.**—The apparatus in use at the Artillery School was made by H. Troemner, of Philadelphia, according to designs furnished by Messrs E. I. Dupont de Nemours & Co., and is used exclusively for the determination of the gravimetric density of small-grained powders such as is used in muskets, mortars, etc. It consists of a small beam-scale resting upon a steel knife-edge, one end of which terminates in a horizontal  $Y$  which is also fitted with steel knife-edges (inverted). Suspended from the latter knife-edges by means of steel-faced trunnions is a vase having the shape of a truncated right cone. The vase has a capacity of 4500 grains of distilled water, and can be readily removed from and replaced in the  $Y$  during the operation. The other end of the beam is graduated into 100 equal parts which are marked from 800 to 900, and are read ounces. Along the top of the beams slides a "rider" by means of which the graduations are read. Immediately below the 900 mark, attached to the under side of the beam, is a small hook, to which may be attached weights marked 100 and 200 ounces, whenever necessary.

To the extremity of the graduated arm is attached a sliding weight, the use of which will appear later. The graduated arm moves between a slotted standard to which is attached an "arrest-er" which is manipulated by a milled-head screw. In addition to the weights mentioned, there is a counterpoise marked 4500 which

is required to produce equilibrium in the preliminary operation of adjusting the balance. In addition to the balance proper, a hopper, fitted with a sliding valve, by means of which the gunpowder may be introduced uniformly into the vase during any series of experiments, accompanies the apparatus. The instrument and its appurtenances are contained in a wooden box about 24"  $\times$  9"  $\times$  9" to protect it from dust when not in use.

**Precautions to be observed in the care and use of the Dupont Gravimetric Balance.**

1. When not in use, see that the vase is removed from the knife-edges on the **Y**, and placed in the seat prepared for it in the case.

2. In removing the vase from its seat on the **Y**, and replacing it, the beam should invariably be arrested, or clamped by turning the milled-head screw to the left. This same precaution should also be observed whenever the counterpoise, or weights are placed, the one in the vase or the others on the beam.

3. In producing equilibrium by means of the sliding weight attached to the extremity of the graduated arm, unclamp and approximate by moving the weight by hand; when equipoise is nearly secured, clamp the weight and produce exact equilibrium by means of the smaller weight which works on the screw-thread projecting from the end of the weight.

4. Equilibrium may be produced in either of two ways, and should there be no occasion for haste, it is well to use one method as a check upon the other.

*First*, place the counterpoise in the vase; attach the smaller (100 oz.) weight to the hook on the under side of the beam and place the "rider" at 800; produce equilibrium by manipulating the sliding weight as just directed.

*Second*, place the counterpoise in the vase; place the "rider" at 900, and proceed as before.

5. Before and after using the instrument, carefully wipe and dust the several parts, including the weights. And before closing the case, see that everything is in its proper place.

**The determination of the gravimetric density of gunpowder with the Dupont Gravimetric Balance.**—Place the vase carefully upon the **Y** and produce equilibrium as above directed. Then

remove the vase, place it upon a large sheet of paper spread upon a table, and place over it the hopper. Fill the hopper with the powder to be examined, open the valve and allow the powder to run into the vase until it is full to overflowing. Close the valve, remove the hopper and "strike" the vase with a straight edge. Replace the vase carefully upon the **Y**, and again produce equilibrium by means of the "rider", and weights, if necessary.

From the construction of the apparatus no calculation is required, and it is only necessary to note the readings on the arm and weight, and express the sum decimally.

Thus, suppose that to reproduce equilibrium when the vase filled with the powder was placed upon the **Y**, it was necessary to attach the smaller weight (marked 100 oz.) and to place the rider at the mark 876 on the arm; the gravimetric density of such a powder would be written immediately 0.976.

**The Gravimetre.**—For determining the gravimetric density of large-grained powders, a copper vessel having the capacity of one cubic foot, and called the *gravimetre* is used in connection with the balance already described with the densimeters. Attached to the left arm of the beam-scale of that balance at the point from which the scale pan is suspended is a hook, the use of which will appear later. The gravimetre is fitted with handles at the opposite extremities of a diameter and rests upon a cradle, by means of which the powder may be settled without breaking the grains by subjecting them to sudden jars or shocks.

The cradle consists of a stout frame made of oak about three feet square. Into the parallel upper frame-pieces are set two metal bearings which receive the trunnions attached to the seat upon which the gravimetre is placed. All motion of the seat may be arrested by means of stay pins. This is necessary whenever it is desired to take the gravimetric density with the powder loose. Uniformity in filling the gravimetre is secured by placing a heavy glass plate across the top of the vessel and noticing whether the granules touch the surface of the glass throughout. The only precautions to be observed in using the gravimetre are those which refer to the balance and have already been enumerated.

**How to use the Gravimetre.**—First carefully dust the gravimetre within and without, and also the scale pans of the balance;



place the gravimetre on the right hand pan, and attach the counterpoise to the hook on the left hand arm. Throw the beam into action, and produce equilibrium, using particles of tin-foil for the purpose if necessary. Having secured equilibrium, throw the beam out of action, remove the gravimetre and place it upon the cradle. Fill the gravimetre loosely, allowing the granules to settle by their own weight, and verifying the full measure by applying the glass plate to the top.

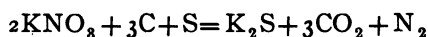
With an assistant, replace the gravimetre thus filled upon the balance, and reproduce equilibrium, using for this purpose the weights which accompany the balance. Note the sum of the weights, and divide by 1000, the result will be the gravimetric density of the powder taken *loose*. Throw the beam out of action, remove the gravimetre from the balance and replace it upon the cradle. Withdraw the "stay-pins", and rock the gravimetre until the powder ceases to settle, keeping the vessel filled to the top by introducing additional powder from time to time. Apply the glass plate as before, and when *evenly* full, replace the gravimetre upon the balance, and reproduce equilibrium. The sum of these last weights divided by 1000 will be the gravimetric density of the powder taken *settled*.

## LECTURE IX.

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### CHEMICAL THEORY OF GUNPOWDER.

Until comparatively recent years, the equation

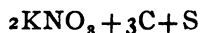


was accepted as expressing the chemical theory of the decomposition of gunpowder resulting from its explosion in the bore of a gun. But the results of the investigations of Noble and Abel have shown that this reaction is far too simple, and that, in addition to the few products obtained as represented in the above equation, much more numerous and far more complex products result from the explosion of gunpowder. For instance, the following substances have been found among the *solid products*: potassium carbonate, sulphate, sulphide, hyposulphate, and sulphocyanate, ammonium carbonate, and sometimes free sulphur and carbon; while among the *gaseous products* have appeared carbon monoxide and dioxide, nitrogen, hydrogen, hydrogen sulphide, and marsh gas.

**Noble and Abel's Calculations.**—This complexity of results led Noble and Abel, after the closest investigation and exhaustive experiments, to the conclusion that "One and the same description of powder, exploded several times in succession, will yield the products of combustion, in the different experiments, in variable proportions; hence the metamorphosis of gunpowder cannot be represented by a chemical equation."

Berthelot differed in opinion from these investigators, and arrived at a different conclusion.

He assumed that the composition of the Waltham Abbey powders was represented as follows:



which requires for 100 parts of powder:

Saltpetre	.	.	.	.	74.8
Carbon	.	.	.	.	13.3
Sulphur	.	.	.	.	11.9

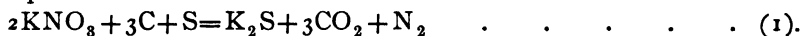
analysis of these powders gave:

Saltpetre	.	.	.	.	.	73.55 to 75.04
Carbon	.	.	.	.	.	10.67 " 12.12
Sulphur	.	.	.	.	.	9.93 " 10.27

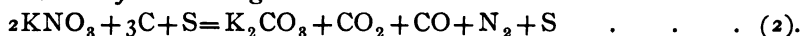
**Berthelot's Theory.**—The following theory was invented by Berthelot to explain the remarkable results of Noble and Abel which led to the still more remarkable conclusion given above. Among the products of explosion enumerated, potassium hyposulphite is not a primary product of the explosion, but is formed during the analysis of the powder residue; while the combined weights of potassium sulphocyanate, ammonium carbonate, hydrogen, and marsh gas amount to only about 1.5 per cent., and as they originate from secondary reactions, may be neglected. There still remains, however, potassium carbonate, sulphate, sulphide, carbon monoxide and dioxide, the formation of which must be accounted for by any satisfactory theory as to the decomposition of a mixture of saltpetre, carbon and sulphur.

According to Berthelot's ingenious theory, if we select two from several experiments of Noble and Abel, viz. one in which the maximum amount of potassium carbonate and the minimum of sulphate were produced, and another which yielded the largest quantity of potassium sulphate and the smallest of the carbonate, then the explosion in the first case may be represented by three equations:—

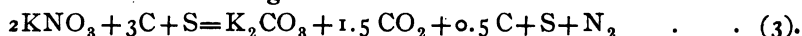
*One-third* of the powder would be transformed according to equation



*One-half* according to



and *one-sixth* according to

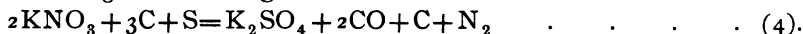


In the second case, with a maximum of potassium sulphate.

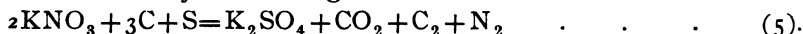
*One-third* of the powder would be transformed according to equation (1)

About *one-half* according to equation (3).

*One-eighth* according to



And *one-twelfth* according to



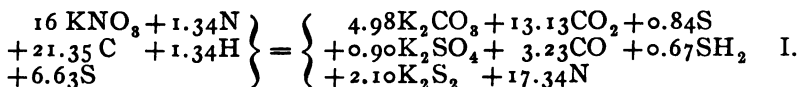
Between the limits marked by these two cases are contained all the experimental results of Noble and Abel. If, therefore, we assume that, in a given experiment, one portion of the powder used burnt according to the equations of the first, and the rest according to those of the second case, the calculated results will agree with those observed. And if the proportions of powder, which are transformed according to the one or other system of equations, be changed from experiment to experiment, the quantities of the products of combustion obtained in each experiment can be calculated in a satisfactory manner.

M. Berthelot justifies his assumption that during explosion one portion of the powder is transformed according to one and another portion according to another equation or system of equations, by a further assumption that the local conditions in a mass of burning powder are not the same in all parts, and that the cooling is too rapid to allow the products to assume a state of chemical equilibrium.

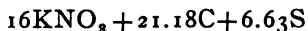
This theory, however, does not agree with experience, since, according to it, considerable amounts of carbon ought to be left free at the end of each explosion, while in twenty-eight experiments of Noble and Abel no free carbon was left, and in only three cases has small insignificant quantities escaped combustion.

**Debus' Theory.**—Thus, discarding the theory of the English investigators, and taking exception to the reasoning of Berthelot, Dr. Debus undertakes to point out the various sources of error in Noble and Abel's methods, and, after applying the necessary corrections, deduces an equation which he claims to represent the metamorphosis of the powders of Waltham Abbey.

This equation deduced from the 31 experiments published by Noble and Abel, is:



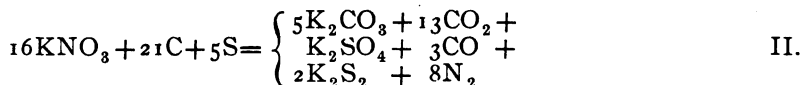
The first member of the equation representing the constituents of the powder has been calculated from the products of explosion. The same constituents, as found by the direct analysis of the powders, are represented as follows:



which agree very closely with those deduced from the products of explosion. Powders of this composition, burnt according to the method of Noble and Abel, will form the products of explosion in quantities as represented in Equation I, if the small quantities of secondary products arising from the presence of hydrogen in charcoal, such as marsh gas, ammonia and free hydrogen are neglected.

The sulphuretted hydrogen is either the product of the direct union of hydrogen and sulphur at comparatively low temperatures, or of the action of carbonic acid and water upon potassium sulphide. In either case its foundation has no direct connection with the explosion, and it ought to be likewise omitted from an equation representing the metamorphosis of gunpowder.

0.84 atom of sulphur is represented as free, because there are no data to show how much sulphur has united with the iron of the apparatus. It is usual to represent the potassium sulphide as monosulphide, while, as a matter of fact, the disulphide is produced. Hence we may substitute for equation I, a much simpler one as follows:



(The difference between equations I and II is due to the union of the sulphur with hydrogen and iron).

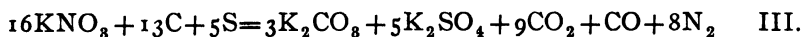
This equation (II) expresses only the quantitative relations between the powder constituents and the products of explosion; the

reactions which occur during explosion, which of them are simultaneous, and the order in which they succeed each other have still to be determined.

It may be assumed that, at first, all the potassium of the salt-petre forms with carbon and oxygen potassium carbonate, and that in another stage, sulphur acts on the potassium carbonate and produces the mixture known as the solid powder residue. Or it may be assumed that potassium sulphate is the first product, and that this is afterwards reduced by carbon to potassium bisulphide and carbonate. Both assumptions would lead to the same results.

For an explanation of the formation of potassium sulphate and carbonate, carbonic acid and oxide, and nitrogen, Dr. Debus examines the results of Karolyi's experiments, according to whose investigations, these substances formed the chief products of explosion of gunpowder.

The equation deduced to represent the metamorphosis of the Austrian powders experimented upon is represented by the equation



From a consideration of these two equations (II and III) Dr. Debus arrives at the first general conclusion as to the decomposition of gunpowder as follows:

*"The combustion of gunpowder consists of two distinct stages; a process of oxidation, which is finished in a very short time, occupying only a very small fraction of a second, and causing the explosion, and during which potassium carbonate and sulphate, carbonic acid some carbonic oxide and nitrogen are produced, and a process of reduction, which succeeds the process of oxidation and requires a comparatively long time for its completion."*

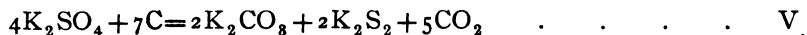
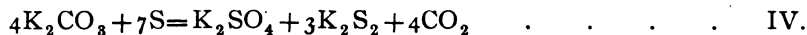
*As the oxygen of the saltpetre is not sufficient to oxidize all the carbon to carbonic, and all the sulphur to sulphuric acid, a portion of the carbon and a portion of the sulphur are left free at the end of the process of oxidation. The carbon so left free reduces, during the second stage of the combustion, potassic sulphate, and the free sulphur decomposes potassic carbonate. Hydrogen and marsh gas, which are formed by the action of heat upon charcoal, likewise reduce potassic sulphate, and some hydrogen combines with sulphur, forming sulphuretted hydrogen."*

Accepting this view, Equation III may be assumed to represent the first, and Equation II, the second stage of the combustion of gunpowder. If, moreover, the combustion of ordinary service powder takes place during the first stage according to equation III, nearly the maximum quantity of heat is obtained which a mixture of saltpetre, sulphur and carbon can produce.

This equation also corresponds to the most simple relation of the heat of formation of the principal products, and also requires the most simple distribution of the oxygen of the decomposed saltpetre. If the combustion of a mixture of saltpetre, carbon and sulphur is to produce potassium carbonate and sulphate, carbonic acid and nitrogen, and if the oxygen of the first three products is to stand to the oxygen of the other in the most simple ratios possible, then the mixture must burn according to an equation, the proportions of which so nearly approach those of Equation III that the latter equation may, without sensible error, be assumed to fulfil all of the foregoing conditions.

The investigator next considers the error arising from assuming that monosulphide of potassium is formed during the combustion of gunpowder, and, from an examination of the results obtained by Berzelius and Mitscherlich, Noble and Abel, and others, shows that, as a matter of fact, potassium disulphide is produced.

From these facts, he concludes that the second stage of the combustion of gunpowder takes place according to the equations:



The possibility of dissociation requires the additional equation,

$$\text{K}_2\text{CO}_3 + \text{K}_2\text{S}_2 + \text{O}_7 = 3\text{K}_2\text{SO}_4 + \text{CO}_2 \quad \text{VI.}$$

The final results of the reactions represented by the foregoing equations may be expressed by one equation as follows:

Let  $x$  represent the number of molecules of saltpetre;

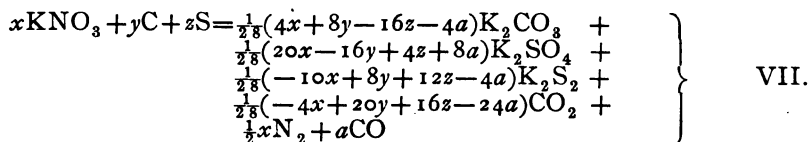
“  $y$  “ “ “ “ atoms “ carbon;

“  $z$  “ “ “ “ “ “ sulphur;

“  $a$  “ “ “ “ molecules of carbonic oxide

formed by the combustion such a powder ( $x, y, z$ , being positive numbers).

The general equation representing the qualitative and quantitative relations between the constituents of the powder on the one hand and the products of *complete* combustion on the other, will then be:



By means of this equation, we can calculate, from that portion of the powder which produces the chief products, the quantities of these products formed during complete combustion. It would be well just here to classify the products of combustion as follows:

- 1st. Chief products:  $\text{K}_2\text{CO}_3$ ,  $\text{K}_2\text{SO}_4$ ,  $\text{K}_2\text{S}_2$ ,  $\text{CO}_2$ ,  $\text{CO}$  and  $\text{N}_2$ .
- 2d. By-products:  $\text{H}_2$ ,  $\text{SH}_2$ ,  $\text{CH}_4$ ,  $\text{NH}_3$ ,  $\text{H}_2\text{O}$ , and  $\text{KCNS}$ .
- 3d. Constituents of powder, not burnt:  $\text{KNO}_3$ ,  $\text{C}$  and  $\text{S}$ .

According to what has already been presented, the metamorphosis of gunpowder may be assumed to take place in a shell, or in the bore of a gun as follows.

In the first moments after ignition, during the explosion, powders of different composition burn according to equation III, and in the case of a shell which will burst almost immediately and its contents be scattered about, no further change takes place. In the bore of a gun the gases expand, move the shot, and by the performance of this work lose a portion of their energy; the products of the first stage of the metamorphosis, potassic carbonate and sulphate, remain at a red heat, in a fluid condition, for a longer time in contact with free carbon and sulphur, and produce, according to equations IV and V, an additional quantity of carbonic acid.

This carbonic acid, which is generated during the movement of the shot in the bore, prevents the too rapid diminution of the tension of the gases; the heat of the solid products is, in part, transformed into *vis viva* of the gas molecules.

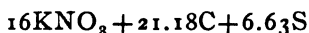
If the gun were long enough and the quantities of carbon and sulphur not too large, every atom of the former might be oxidized by the oxygen of the potassium sulphate, and the entire



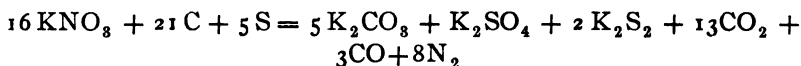
amount of the sulphur be converted into potassium disulphide and sulphate by contact with potassium carbonate. But in reality this second stage is never complete; the shot will have left the bore before the termination of these comparatively slow reactions.

#### Recapitulation.—

1. The mean mean composition of the Waltham Abbey powders can be represented as follows:



a powder of this composition is transformed in Noble and Abel's apparatus according to the equation:



The residue of the sulphur, 1.63 atoms, unites partly with hydrogen, partly with the iron of the apparatus.

2. The ordinary service and sporting powders contain for every 16 molecules of saltpetre from 13 to 22 atoms of carbon, and from 5.5 to 8.7 atoms of sulphur.

3. A powder composed of *pure* carbon, saltpetre, and sulphur furnishes by its complete combustion potassium carbonate, sulphate and disulphide, carbonic acid and oxide, and nitrogen, as chief products.

4. An increase of pressure appears, *ceteris paribus*, to diminish the amount of carbonic oxide, and in consequence, according to equation VII, to increase the quantities of potassium carbonate and disulphide, and carbonic acid, and to diminish that of potassium sulphate.

5. The combustion of gunpowder takes place in two stages, one succeeding the other.

- (a) A process of oxidation during which potassium sulphate and carbonate, carbonic acid, and nitrogen, and, *perhaps*, some carbonic oxide, but no potassium disulphide, are produced.
- (b) A process of reduction during which carbon and sulphur left free at the end of the first stage react with some of the products formed during that stage; the free carbon reducing potassium sulphate, with form-

ation of potassium disulphide and carbonate, and carbonic acid; the free sulphur decomposing potassium carbonate with the production of potassium disulphide and sulphate, and carbonic acid. (Equations IV & V).

6. The first stage of the combustion, the explosion proper, takes place with powders of various compositions according to the equation:

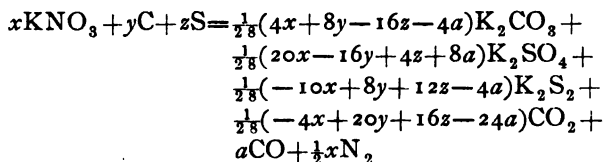


But as some carbonic oxide is probably produced at the same time, Equation III will more nearly represent the reaction.

7. In the equation given immediately above the oxygen in the potassium carbonate stands to the oxygen in the potassium sulphate in the most simple ratios which can exist, if these substances are to be produced by the combustion of a mixture of saltpetre, carbon and sulphur. In other words, this equation represents the most simple distribution of the oxygen of the decomposed saltpetre among the products of the first stage of combustion. The products as represented by equation III are very nearly in the same proportions as in the last equation, therefore it follows that the distribution of the oxygen between potassium carbonate and sulphate, and carbonic acid, according to Equation III, very nearly corresponds to the most simple possible distribution,

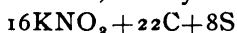
8. Ordinary gunpowders contain more carbon and sulphur than is required by equation III. This excess of carbon and sulphur is left free at the end of the first stage of combustion. The free carbon then acts according to equation V, and the free sulphur according to equation IV, and both together form the second stage of combustion. These reactions are endothermic; heat is not evolved, but consumed; they are not of an explosive nature, and in practice are probably seldom complete. The reactions in the second stage increase the volume of the gas formed during the first stage of the combustion and diminish the temperature of the products. A portion of the carbonic oxide is formed during the second stage by the action of free carbon, or potassium disulphide upon carbonic acid.

9. The reactions represented by equations II, III, IV and V can be expressed by one equation as follows:

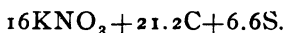


in which  $x$ ,  $y$  and  $z$  are positive numbers, and represent respectively the number of molecules of saltpetre, the number of atoms of carbon, and the number of atoms of sulphur contained in such a powder; while  $a$  represents the number of molecules of carbonic oxide formed by the combustion of such a weight of the powder.

10. If a mixture of saltpetre, carbon and sulphur were required which shall possess nearly the greatest energy, and at the same time contain the smallest amounts of carbon and sulphur compatible with this condition, theory would point to the mixture



The service powders of most nations fluctuate about



## LECTURE X.

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### CHLORATE MIXTURES.

Berthelot first suggested that the nitrates in gunpowder mixtures might be replaced by chlorates, and experimentally demonstrated the advantages and disadvantages which would result from the substitution.

The employment of potassium chlorate in explosive mixtures has always offered great attractions, owing to the violence of its effects due to the rapidity of its action.

The explosives resulting from the use of the chlorates may, broadly speaking, be divided into two classes, those in which no particular attempt is made to diminish the dangerous sensibility of the chlorate mixtures, and those in which by the addition of some diluting ingredient or by some special mechanical treatment, endeavors are made to diminish this sensibility. In spite of all efforts to regulate the action of the chlorates, the danger attending the manufacture, storage and manipulation of these mixtures cannot be eliminated.

Dr. Duprè, F. R. S., an authority on the subject of explosives, says in this connection: "Chlorate of potassium on account of the readiness with which it lends itself to the production of powerful explosives offers a great temptation to inventors of new explosives, and many attempts have been made to put it to practical use, but so far with very limited success. This is chiefly owing to two causes. In the first place chlorate of potassium is a very unstable compound, and is liable to suffer decomposition under a variety of circumstances, and under, comparatively speaking, slight causes, chemical and mechanical. All chlorate mixtures are liable to what is termed spontaneous ignition, or explosion in the presence of a variety of materials, more particularly of such as are acid or are liable to generate acid; and all chlorate mixtures are readily

exploded by percussion, but more particularly by combined friction and percussion, such as a glancing blow which might easily and would often occur in charging a hole.

In the second place there is some evidence to show that the sensitiveness to percussion and friction increases by keeping, more especially if the explosive is exposed to the action of moist and dry air alternatively."

The increased sensitiveness caused by keeping and exposure to moisture is probably due, in part at least, to the chlorate crystallizing out into fine crystals on the surface of the mixture.

Eissler, on the same subject, says:—"It is extremely doubtful from the peculiarities of this salt, if anybody will ever overcome the obstacles due to its inherent chemical properties, which nature manifestly seems to have made unconquerable.

"In mixing these compositions great danger is attendant, and too much circumspection cannot be used. They explode instantly on any violent stroke, very often by friction alone; sometimes spontaneously as when in a state of rest, and no known cause for their combustion can be ascertained.

"Many are deluded as to its safety by so-called experiments with freshly made powder. Manufacturers of this compound may attempt to show its safety by hammering and cutting it and similar tests; but let the powder be exposed to the natural atmospheric action, attract some moisture during a damp foggy night, then get dry, and the least friction or blow will cause an unexpected explosion".

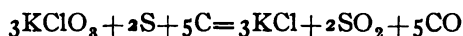
To this Major Cundill, R. A., H. M.'s Inspector of Explosives, adds:—"Without going so far as to say that it is impossible to manufacture a safe chlorate mixture, it is a fact that out of many which have been examined with a view to their introduction into this country, not one has yet been found to be safe enough to be licensed with the exception of asphalene. \* \* \* \*

"I do not pretend to say that powerful and valuable explosives may not be, and have not been, manufactured with chlorate of potash as their main ingredient, but I contend that though these are fairly safe when used for special purposes and by experts, none have as yet been brought to notice (with the previously

named exception) which are suitable for general use by the mining population, and which could be relied upon not to cause accidents under ordinary conditions of transport, storage and use".

According to Berthelot, a powder in which the nitre is replaced by an equivalent quantity of chlorate should have a heat of combustion greater by one-half than that of the gunpowder, and should possess double the force.

The reaction resulting from such a substitution may be represented as follows:



which corresponds fairly well to a powder having the composition of

KClO <sub>3</sub>	.	.	.	.	75.00	parts
S	.	.	.	.	12.50	"
C	.	.	.	.	12.50	"

Besides the erosion of the walls of the gun by the chlorate powders, the chlorine sometimes liberated after firing, is deleterious to those exposed to its action.

These disadvantages, together with those already enumerated, are not compensated for by the superior explosive power of the mixtures.

Several chlorate mixtures, however, have been proposed and patented, some of which are given.

**Asphaline.**—This substance consists of thoroughly cleansed wheat or barley bran impregnated with potassium chlorate mixed with potassium nitrate and sulphate. Paraffin oil, paraffin, ozokerit and soap, or some of these substances may be added. The mixture in commerce is colored pink with fuchsine.

The proportions of the several ingredients are

Potassium chlorate	.	.	.	.	54	parts
Bran	.	.	.	.	42	"
Potassium nitrate	}	.	.	.	4	"
Potassium sulphate		.	.	.		

In reporting upon this powder, H. M.'s Inspectors of Explosives in their Report for 1890 note that two samples of asphaline were examined which had been kept in store for a number of years. One of the two was quite mouldy. Nevertheless, both samples were in good condition as far as their safety was concerned, and they gave little or no indication of increased sensitiveness to friction or percussion such as is often noticed in chlorate mixtures.

**Melland's Paper Powder.**—The following mixture is boiled for an hour in 79 parts of water:

Potassium chlorate	.	.	.	.	9.00 parts
“ nitrate	.	.	.	.	4.50 “
“ ferrocyanide	.	.	.	.	3.25 “
“ chromate	.	.	.	.	0.06 “
Charcoal	.	.	.	.	3.25 “
Starch	.	.	.	.	0.05 “

Strips of porous paper are then dipped in the liquor, rolled in to the form of cartridges and dried at 100° C. To prevent their absorbing moisture they are given a coating with a solution formed by dissolving one part of xyloidine in three parts of acetic acid (Sp. gr. 1.04). This paper is cheap, easy to make and fairly safe. It does not give off much smoke or leave much residue, nor does it erode the piece in which it is fired, while it is more powerful than gunpowder.

**Augendre's Powder.**—This is also known as White German or American Powder, and consists of

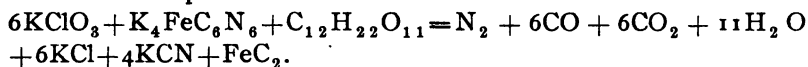
Potassium chlorate	.	.	.	50 parts.
“ ferrocyanide	.	.	.	25 “
Cane-sugar	.	.	.	25 “

The substances are moistened and mixed in bronzed mortars and granulated.

Pohl, who submitted this powder to many trials, modified the composition as follows:

Potassium chlorate	.	.	.	49 parts
“ ferrocyanide	.	.	.	28 “
Cane-sugar	.	.	.	23 “

being in the proportion of three equivalents of the chlorate to one of each of the others. Pohl represented the products of combustion of such a powder as follows:



From his calculation 100 grammes of the powder give 52.56 grm. of solid products and 47.44 grm. of gas, which has a volume at 0° and 76 cm. of 40680 c. c. and at the temperature of combustion (valued at 2604.°5 C) a volume of 431162 c. c. These conclusions are all in favor of the White Powder, but they have never been verified.

Sixty parts by weight, or 77.4 by volume, are equivalent to 100 parts of gunpowder, and they give but 31.35 parts of solid residue, where 100 parts of gunpowder, according to Bunsen and Schischkoff, give 68 parts. Besides the temperature of the resulting gas is not so high for the white powder, and hence a greater number of shots may be fired without heating the piece excessively. The ratio of the temperatures is as 0.779 to 1. But the estimation of the temperature is based on the hypothesis held as to the nature of the reaction, and on the calculated temperature of the reaction, neither of which have been demonstrated exactly.

If the process goes on precisely as Pohl believes, it is difficult to explain the erosive action of this powder upon guns from which it is fired.

Augendre and Pohl claimed other advantages for this powder, viz., it keeps perfectly in free air, inflames easily on contact with a spark, can be employed without being granulated, is simple to manufacture and is inexpensive.

According to Pohl, the manipulation of this powder presents absolutely no danger if the substances are pure and contain neither sulphur nor carbon, and they cannot be exploded by a blow of iron on iron or by friction.

Experience does not confirm these assertions. Several instances of explosion are known to have taken place when the materials were mixed with great care; and a bottle filled with the powder has exploded when exposed to the sun in summer. Even if the undoubted dangers, which exist in the use of white powder, were overcome, still the erosive action which it exerts on the gun would



tend to proscribe it for this use. The erosive action of the powder is most marked on cast-iron and steel guns, and it has therefore been proposed to limit its use to bronze guns and to the charging of shells, for which it seems especially appropriate. According to Hudson, glass bulbs filled with concentrated sulphuric acid are placed in the shells with white powder, and the shock of impact, when the shells strike the object to be destroyed, is sufficient to break the bulb, liberating the acid which upon coming into contact with the powder ignites it and causes explosion.

**Dynamogen.**—M. Pétry has devised the following process for manufacturing an explosive paper, which he calls *dynamogen*.

He dissolves yellow prussiate of potash in pure water, and heats the solution until it boils, when he adds powdered charcoal, stirring the mixture well. Allowing this to cool, he next adds successively potash, chlorate of potash and starch, triturated in water.

The proportions are as follows:

Potassium ferrocyanide	17 parts
Water	150 "
Charcoal	17 "

boiled, well stirred and allowed to cool, to which is added

Potash	35 parts.
Potassium chlorate	70 "
Starch	10 "
Water	50 "

The whole mixture is made into a thin paste, and spread with a brush on ordinary filtering paper. The paper is dried on a moderately heated plate, and as soon as one side is thoroughly dry, the other side is varnished in a similar manner. Three coats are given each side, and the paper so impregnated is cut up and rolled into cartridges.

**Hahn's Powder** consists of:

Potassium chlorate	367.5 parts
Antimony tersulphide	168.3 "
Spermaceti	46.0 "
Charcoal	18.0 "

The last three substances are thoroughly mixed, and the chlorate added just before the powder is to be used, the mixing being done by sieves. The addition of the spermaceti is claimed to protect the mixture against explosion by friction.

**Horsley's Powder** consists of a mixture of finely powdered potassium chlorate and gall-nuts in the proportions of three to one.

The powder may be granulated by passing it through a sieve while in a damp state. The ungranulated form of powder experimented with in Austria for use in small-arms was not satisfactory. The granulated powder is stated to explode at  $221^{\circ}\text{C}$ , and its *force* to be five times that of gunpowder.

**Pertuiset's Powder** is recommended for use mainly as a *detonating* powder, or for filling bullets or shells. It has, in the past, been used in the manufacture of explosive bullets. It consists of

Potassium chlorate	.	.	.	.	2.000 parts
Sulphur	.	.	.	.	1.000 "
Sporting gunpowder	.	.	.	.	0.125 "
Animal charcoal	.	.	.	.	0.020 "

**Parone's Explosive** consists of two parts of potassium chlorate and one of carbon disulphide.

From experiments in Italy with the 9-cm. and 15-cm. projectiles, it was concluded that this mixture was an exceedingly safe one; that it would not explode without a fuse—not always a desirable quality—and that although its effects were not strikingly superior to those of gunpowder, they increased rapidly with an increase of calibre.

**Petrofracteur**, a chlorate powder recently endorsed by the Austrian military committee, consists of

Potassium chlorate	.	.	.	.	67 parts
Nitrobenzene	.	.	.	.	10 "
Potassium nitrate	.	.	.	.	20 "
Antimony sulphide	.	.	.	.	3 "

As in the case of the nitrates, so with the chlorates, the list of proposed mixtures is well nigh unlimited. By far the majority of these powders have proven worse than useless, for reasons already given. *Those mixtures intended for use as fuse compositions are the only ones that have become of any practical value.* Among this class may be mentioned:

**Davey's Fuse composition**, which consists of

Potassium chlorate . . . . .	6 or 6 parts
“ nitrate . . . . .	5 “ 3 “
“ ferrocyanide . . . . .	2 “ 4 “
“ bichromate . . . . .	5 “——“
Antimony sulphide . . . . .	5 “ 3 “

**Hill's Fuse compositions**, which were prepared by Mr. Hill, while chemist to the U. S. Naval Torpedo Corps, and were designed for the several systems of torpedoes.

**Fuse composition for the Contact System.**—This system requires a composition more sensitive than that used in either the percussion cap or cannon primer.

The following mixture proved satisfactory, and is made by finely powdering and mixing together, under alcohol.

Potassium chlorate . . . . .	60.50 parts
Antimonious sulphide . . . . .	33.50 “
Phosphorus (amorphous) . . . . .	6.00 “

**Composition for Friction Fuses.**—Satisfactory results were obtained when the following mixture was used to explode spar torpedoes.

Potassium chlorate . . . . .	44.44 parts
Manganic oxide . . . . .	44.45 “
Phosphorus (amorphous) . . . . .	11.11 “

The ingredients must be finely powdered separately, mixed under alcohol, and used while wet.

**The Sulphuric Acid Fuse.**—This belongs to a class of fuses known as chemical fuses. The substances are separated and kept apart until required for action, when they are brought into contact, and unite chemically with the evolution of heat and production of flame. Such action occurs when sulphuric acid is brought into contact with a mixture of equal parts of potassium chlorate and cane-sugar. When these materials only are used, the action of the fuse is somewhat sluggish, particularly when the fuse has been manufactured for any length of time. But if the following ingredients, in the proportions given, be used, the ignition will be instantaneous.

Potassium chlorate . . . . .	41.4 parts.
“ ferrocyanide . . . . .	17.2 “
Cane-sugar . . . . .	41.4 “

**Composition used in the Harvey Fuse.**—The principle of this fuse is precisely the same as that just described. The sulphuric acid reacts upon the following mixture.

Potassium chlorate . . . . .	17.0 parts.
Cane-sugar . . . . .	4.5 “
Nut galls . . . . .	1.5 “

**Composition for Fuses to be exploded by Frictional Electricity.**—The following mixture is used in all igniters made at the U. S. Naval Torpedo Station for use with frictional machines.

Potassium chlorate . . . . .	45.00 parts.
Antimonious sulphide . . . . .	20.75 “
Phosphorus (amorphous) . . . . .	5.75 “
Carbon . . . . .	28.50 “

The ingredients are finely powdered separately, mixed under alcohol, and used while wet.

**English Priming material** originally consisted of

Copper subphosphide . . . . .	10 parts
“ subsulphide . . . . .	45 “
Potassium chlorate . . . . .	45 “

The proportions of the ingredients are now varied, in order to produce compositions of different degrees of sensitiveness. The ingredients are prepared and mixed as described above.

**Austrian Priming Material** consists of

Potassium chlorate . . . . .	1 part
Antimony sulphide . . . . .	1 “
Plumbago (powdered) . . . . .	trace.



## LECTURE XI.

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### EXPLOSIVE COMPOUNDS.

The explosive substances, thus far treated of, have been produced by mixing together mechanically combustible substances with oxidizing salts. We shall now consider that class of explosives, known as *explosive compounds*, in which the oxidizing agent is introduced chemically into the molecule, thus forming no longer a mixture, but a true chemical compound, each molecule of which contains the oxidizing atoms and atoms having a strong affinity for oxygen. It is evident that the relation existing between the constituents in the latter case must be far more intimate than in the former.

As has been already stated, the chief *explosive compounds* are formed by the action of nitric acid upon various organic substances containing carbon, hydrogen and oxygen. This combination of the oxides of nitrogen with the hydrocarbon groups may give rise to two *classes* of explosive compounds, viz:

*Nitro-substitution compounds*, in which the nitrogen oxide is attached directly to the carbon atoms, and

*Nitric Ethers or Esters*, in which the nitrogen oxide is connected with the carbon atoms through the interposition of oxygen atoms.

#### Nitro-substitution compounds.—

**Picric Acid.**—One of the best examples of this class of explosive compounds is *Picric Acid*, which was discovered by Hausmann in 1788. He made it by treating indigo with nitric acid. It may be obtained in various ways, but the cheapest and best source is from the action of nitric acid on phenol, or “carbolic acid,” one of the products of the distillation of coal tar. The reaction may be represented by the following equation,



It may be prepared experimentally by introducing into a glass flask of 150 c. c. capacity about 5—10 c. c. of fuming nitric acid, and adding cautiously in very small quantities, about 1—2 c. c. of carbolic acid. The reaction is very violent, and is attended with the copious development of nitrous fumes. When the reaction has subsided, and the flask become cold, yellow crystals of picric acid will be found in the liquid.

Picric acid is made commercially by melting carbolic acid and mixing it with strong sulphuric acid; then diluting the "sulpho-carbolic" acid with water, and afterwards running it slowly into a stone tank containing nitric acid. This is allowed to cool, when the crude picric acid crystallizes out, the acid liquid (which contains practically no picric acid, but only sulphuric with some nitric acid) being poured down the drains.

The crude picric acid, after being drained, is transferred to the "boiling stones," where it is dissolved in water by the aid of steam and afterwards allowed to cool, when most of the picric acid recrystallizes.

The "mother liquor" is then transferred to the precipitating tank, in which the picric acid still left in solution is precipitated by the addition of sulphuric acid.

The picric acid left in the "boiling stones" is once more dissolved in hot water, and this second solution is transferred to the crystallizing tank, where it is left to cool, and where the picric acid again crystallizes. Finally, the picric acid, after draining in the tank, is transferred to a centrifugal machine to remove the excess of moisture, and then dried on glazed earthenware trays in a steam box in which the temperature is not allowed to exceed 100° F. According to Hill and Abel, picric acid does not explode, but, when heated, it burns quickly and sharply with a bright flame.

An investigation into the subject of the explosiveness of picric acid undertaken by Col. Majendie and others tends to show that picric acid could not be exploded by heat, even when confined in large masses, but it was by no means proven that it could not, under certain circumstances, be exploded by the action of fire.

Desortiaux states that, when heated *slowly*, it vaporizes without undergoing any decomposition, but, when heated *brusquely* to a temperature a little above 300°, it explodes with violence.

Berthelot has also recently studied this subject, and confirms the view of Desortiaux. He says: "Should a nitro-compound, such as picric acid, while burning in large masses, happen to heat the sides of the containing enclosure to a degree sufficient to induce deflagration, the deflagration might combine to further increase the temperature of the enclosure, and the phenomenon might, occasionally, be transformed into a detonation. It would even suffice that the detonation should occur in an isolated point, either during a fire, or owing to the local overheating of a boiler or apparatus, to enable it to originate the explosive wave and propagate itself by influence throughout the whole mass, causing a general explosion."

There exists no doubt, however, that picric acid is liable to be exploded by detonation or by a blow, and that the picrates and the mixtures of picric acid, with oxidizing agents, are highly explosive.

In 1873 Sprengel stated that "picric acid alone contains a sufficient amount of available oxygen to render it, without the help of foreign oxidizers, a powerful explosive when fired with a detonator. Its explosion is almost unaccompanied by smoke."

Apart from the investigation above referred to, the detonation of picric acid has recently attracted attention from the alleged use of this substance by the French government in a particular fused and consolidated condition, as an explosive, under the name of *mélinite*.

M. Eugene Turpin has also taken out a patent, which claims the employment "as an explosive agent for military or other uses of the trinitrophenol, or picric acid, of commerce, unmixed with any oxidizing substance," by the use of a powerful fulminate detonator, or by the use of an intermediate priming of picric acid in powder, primed by the fulminate, or by dispensing with the fulminate and employing a sufficiently large charge of ordinary quick-burning powder enclosed in a strong tube and made to burst inside the charge of picric acid.

The explosiveness of picric acid, by detonation, has been investigated experimentally with the following results:

- 1st. Dry picric acid may be perfectly detonated by means of a 5-grain fulminate detonator.



- 2d. The detonation of a small quantity of dry picric acid is capable of detonating a quantity of picric acid placed at a short distance from it.
- 3d. The detonation of picric acid containing, at any rate, as much as 17 per cent. of water may be effected by detonating a charge of dry picric acid.
- 4th. A thin layer of cold picric acid will be exploded by a weight of 54 pounds falling 20 feet, and *it may be exploded* by one pound falling 26 inches. The sensitiveness greatly increases with warming, so that, when heated to a temperature just below its melting point (about 240° F.), a weight of one pound falling 14 inches will explode it.

**Borlinetto's Powder.** As far back as 1867, Borlinetto proposed a mixture of picric acid and other oxidizing agents for blasting purposes. The ingredients and the proportions in which they were to be mixed are as follows:

Picric acid,	10.0 parts.
Sodium nitrate,	10.0 "
Potassium chromate,	8.5 "

The resulting powder proved too sensitive to be of practical value.

Many salts, known as *picrates*, have been derived from picric acid, but the only ones which have been used to any extent for explosive purposes are the salts of potassium and ammonium. All of the picrates, except  $C_6H_2(NO_2)_3ONH_4$ , are readily exploded by heat or blows.

**Potassium Picrate**— $C_6H_2(NO_2)_3OK$ . This is one of the most violently explosive of the picrates. It is made by mixing warm potassium carbonate with a boiling solution of picric acid in water. On cooling, the liquid deposits small crystalline needles of a golden yellow color which show green and red colors by reflected light. Heated gradually to 310° C. it explodes violently; and it may also be detonated by a sharp blow.

When mixed with oxidizing agents, and especially potassium chlorate, its explosive properties are very much increased. Such a mixture approaches very nearly to nitroglycerine and gun-cotton in violence, but it is so sensitive to friction and shocks as to

be practically useless. When containing 15 per cent. of moisture, potassium picrate is safe from detonation by blows, and ignites only locally on contact of flame.

Several mixtures containing the potassium salt have been experimented with, but with no great degree of success.

**Fontaine's Powder**, consisting of potassium picrate and chlorate, was made and tested in Paris as a charge for shells and torpedoes, but it was very dangerous to manipulate, and, after a terrible accident in 1869, it was abandoned.

**Designolle's Powder.** This powder is made on a large scale at Le Bouchet in France, and is graded according to the proportions of the ingredients, which are potassium picrate and nitrate, with or without the addition of charcoal.

The compositions of the four varieties made at this factory are as follows:

DESIGNOLLE'S POWDER.	TORPEDOES AND SHELLS.		CANNON.			SMALL ARMS, MUSKET, &C.	
			Ordinary calibre.		Large cal.		
Potassium picrate,	55	50	16.4	9.6	9.0	28.6	22.9
“ nitrate,	45	50	74.4	79.7	80.0	65.0	69.4
Charcoal, . . .	—	—	9.2	10.7	11.0	6.4	7.7

These powders were made according to the ordinary processes followed in the manufacture of gunpowder, from 6 to 14 per cent. of water being used, and the trituration being three hours for torpedo powder, six hours for musket, and nine hours for cannon powder. The powder was granulated as usual. The torpedo and shell powder were tried at Brest and Toulon with excellent results. According to Roux and Sarrau, the heat of combustion of the 55 per cent. mixture will be 916 cal., and of the 50 per cent. 1180 cal.

The cannon and musket powders were noted for their uniformity of action, the variations in the initial velocities of the projectiles being not more than two metres. According to Jouglet, 60 grammes of Designolle powder produced the same result as 350 grammes of ordinary powder, while the force of these mix-

tures could be varied between quite wide limits according to the amount of picrate which they contained. In spite of their superior ballistic properties, Designolle powders appear to be less brisant than black powder. They give scarcely any fumes while burning, and do not erode the piece in which they are fired.

The picrates constitute a series of crystalline bodies of definite composition and known reactions, and there is no reason to apprehend that they may decompose "spontaneously."

**Ammonium Picrate**— $C_6H_2(NO_2)_3ONH_4$ —is prepared by saturating warm picric acid with concentrated ammonia water. When neutralization is complete another charge of picric acid is dissolved in the same liquid and ammonia again added. The solution is allowed to stand and cool, when the salt crystallizes out in transparent orange colored prisms. It may also be obtained crystallized in beautiful citron-yellow needles by treating picric acid with ammonium carbonate. According to Hill and Abel, if flame is applied to ammonium carbonate, it burns without any tendency to explosion. It is almost insensitive to blows or friction. According to Desortiaux, it explodes when heated to about  $310^\circ C.$ , but if heated in free air to a temperature below  $300^\circ C.$ , it fuses and burns.

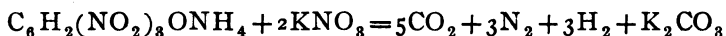
**Brugere Powder.** This powder has been made to some extent in France, and has been found to be stable, safe to manufacture and handle, but rather expensive. It consists of

Ammonium picrate,	. . . . .	54 parts,
Potassium nitrate,	. . . . .	46 "

Heated to  $310^\circ C.$  this mixture burns with one-half the velocity of ordinary powder. Its force is about twice or three times that of black powder. It is but slightly hygroscopic, leaves but little residue (which is not erosive), and gives off a small amount of inodorous gas. Experiments with the Chassepot showed that 2.6 grammes of this powder produced the same effect as  $5\frac{1}{2}$  grammes of regulation powder.

Brugère powder is said to give a velocity of more than 2,000 feet per second with small arms, and to cause very slight recoil. Large numbers of cartridges of this powder were ordered for the new Lebel rifles, but it is stated that a recent examination of a quantity of this ammunition that had been stored at Chalons showed that the powder had deteriorated to such an extent that the whole lot had to be condemned.

Brugère expresses the reaction produced by the explosion as follows :



Hence 100 grammes of the powder should give 69.14 grammes of gaseous products, which, at 0° and 76 cm., would have a volume of 52.05 litres. A direct determination gave 48 litres. Compared with the analogous results obtained by Bunsen and Schischkoff for black powder, the ratio of the volumes is as 2.5 : 1. It is extremely doubtful, however, whether a reaction (as above given) will yield  $\text{CO}_2$  and H at the same time.

**Abel's Powder.** About the same time that Brugère introduced his powder, Abel patented a similar powder in England, which consisted of a mixture of ammonium picrate, potassium nitrate and charcoal. When flame is applied to particles of this mixture, they deflagrate with a hissing sound, but the deflagration has but little tendency to spread to the contiguous particles ; but if the mixture be strongly confined, as in shells, it explodes violently, and exerts a destructive action, less powerful than that of gun-cotton, nitroglycerine preparations, and Designolle powder, but considerably greater than that of gunpowder. It is to be remarked that while ammonium picrate and potassium nitrate mixed in these proportions undergo mutual decomposition, with the production of the highly deliquescent salt, ammonium nitrate, yet if the two be *dissolved* together in water, the addition of sufficient water to even thoroughly moisten the mixture appears to induce no such change, since, when again dried, the mixture seems to have no greater tendency to absorb moisture from the air. Indeed the powder is no more hygroscopic than black powder, and appears to be fully as stable, while the fact that water

may be used in incorporating the ingredients without any detriment to the final product renders its manufacture, at least, not more dangerous than that of ordinary gunpowder, and it may be subjected to the same processes of pressing and granulating as are applied to the latter.

Shells charged with picric powder have been fired in England from guns of different calibres up to the 9-inch gun, with a charge of 43 pounds of R. L. G. powder, and without an accident of any kind. Some comparative experiments have also been instituted between this powder and compressed gun-cotton in sub-marine mines, the results of which indicated that the destructive action of the two was not very different, when applied under the pressure of water. For use in large sub-marine mines, *wet* gun-cotton is undoubtedly more efficient, but for use in small offensive torpedoes, the granular form of the picric powder can be used to great advantage in completely filling the case.

Professor Hill made Abel's powder as follows :

Ammonium picrate,	. . . . .	42.18 parts,
Potassium nitrate,	. . . . .	53.97 “
Charcoal (best alder),	. . . . .	3.85 “

These ingredients were moistened with water and worked under wheels, granulated, etc., as in the manufacture of ordinary powder. Thus obtained the powder had a yellowish-green color, was easily granulated, and no difficulty was experienced in working it.

Compared with gun-powder as to the amount required as a bursting charge for cast-iron spherical shells, the force of this powder was found to be to that of gunpowder as 1.75 to 1. It appeared, however, to burn imperfectly, giving off a heavy greenish-yellow smoke, which was supposed to be due to imperfect working of the mixture under the wheels, and to too small a proportion of  $\text{KNO}_3$ , as is evident from an examination of the proportions used.

As a charge for fuses and igniters, excellent results were obtained. As may be inferred from what has already been said, nitro-substitution compounds may be derived from almost every substance rich in carbon and hydrogen, but as yet very few such

compounds have become prominent except those derived from benzole, naphthaline, etc., which are now being largely used as important constituents of such explosives as bellite, securite, roburite, etc.

**Mono and di-nitro-benzenes.** Thus by acting on benzene with strong nitric acid, we obtain the *mono-nitro-benzene*,  $C_6H_5(NO_2)$ . This is an oily liquid having a yellowish color, and is characterized by a powerful odor such as is emitted by the essential oil of bitter almonds. This product is commonly known as *Mirbane Oil*, and is one of the principal ingredients of Rack-a-Rock; but as this explosive belongs to a special class, we shall omit further remarks upon it until we come to the consideration of the Sprengel Explosives.

By acting upon the mono-nitro-benzene with strong nitric acid, we obtain three different solid *di-nitro-benzenes*, viz: the ortho, meta, and para, all being expressed by the same formula,  $C_6H_4(NO_2)_2$ . They are all soluble in alcohol, from which solution, on cooling, the meta-compound crystallizes out first, while the ortho- and para-di-nitro-benzenes remain in solution. The meta-compound melts at  $90^\circ C.$ , and when free from nitric acid, can be kept unchanged for any length of time. The tri-nitro-compound is easily obtained from the meta-compound by heating it to  $140^\circ C.$  with concentrated nitric and fuming sulphuric acids.

**Bellite** is a Swedish explosive which was discovered by Carl Lamm, of the Rötbro Explosive Manufactory, Limited, near Stockholm, and consists of a mixture of ammonium nitrate and meta-di-nitro-benzene in the following proportions:

Ammonium nitrate,	. . . . .	5 parts,
Meta-di-nitro-benzene,	. . . . .	1 "

These ingredients are heated up to  $80^\circ$  or  $90^\circ C.$  (the melting point), and, when in a melted condition, are mixed with saltpetre, forming a true explosive compound. When pressed warm and granulated, it has a specific gravity of from 1.2 to 1.4, and a gravimetric density of from .800 to .875.

Heated in an open vessel, bellite loses its consistency at  $90^{\circ}\text{C.}$ , but does not begin to separate below  $200^{\circ}\text{C.}$ ; at that point evaporation begins, and increases with a higher temperature, without explosion however. Suddenly heated, bellite burns with a sooty flame, but upon the removal of the source of heat, it ceases to burn and assumes a caramel-like structure, the ingredients being the same as in its original state with the exception of a smaller proportion of saltpetre. After it has been pressed, bellite is not especially hygroscopic; if pressed while hot, the subsequent increase of weight does not exceed 2 per cent.

During February 1889, an experimental exhibition of the properties of bellite was given at Chadwell Heath, England, and the following tests were made in the presence of a large number of visitors:

1. A charge of  $1\frac{1}{2}$  pounds of the explosive was placed in a can and fired under water. The can being water-tight, this experiment might have been omitted.
2. A 4-ounce charge of bellite—which somewhat resembled a stick of sulphur—was broken in two, and one end thrown into a coal fire, where it melted and burned quietly. The other end of the stick was placed upon a  $\frac{3}{8}$ -inch iron plate and exploded by means of a detonator. The plate was bulged. This experiment illustrated the fact that while bellite cannot be exploded by ordinary combustion, yet when detonated by proper means, it exerts a powerful force.
3. A mass of iron weighing 120 pounds was dropped from a height of about 16 feet upon five charges of bellite placed on an iron plate. The explosive was ground to pieces without explosion.
4. Five ounces of this crushed bellite was placed in a can and detonated in contact with a steel-faced iron rail, the rail being fractured by the force of the explosion.
5. A quantity of bellite was mixed with one pound of blasting powder and buried in a hole three feet deep. This charge was fired by a plain powder fuse, but the bellite, although blackened and burned somewhat on its surface, was thrown about unexploded.

6. A charge of bellite was fired like a bullet from a small-arm against a  $\frac{3}{8}$ -inch iron plate. Pieces of the explosive were found adhering to the plate unexploded.
7. The ballistic properties of bellite were illustrated by firing from a mortar a 32-pound shot, first with a charge of  $\frac{1}{2}$  pound of powder, and then with a  $\frac{1}{4}$  pound of bellite. In the first case the range attained was  $40\frac{1}{3}$  yards; in the latter 95 yards.
8. Its explosive effect was next compared with that of dynamite under similar conditions. Four ounces of each explosive were placed upon  $\frac{3}{8}$ -inch iron plates, covered with moist clay, and detonated. The effects were about the same, although it was claimed that the explosive effect of bellite was more widely distributed than that of dynamite.
9. It was next tried to explode bellite in mines by means of ordinary powder fuses. In all cases the bellite failed to explode, while gunpowder was readily exploded under similar circumstances.
10. A charge of 8 pounds of bellite was placed in a mine 3 feet deep beneath a length of railway line laid in chairs fixed in cross sleepers with fishes, etc., complete, and exploded by means of a detonating fuse. The entire structure for many feet was thrown in the air, the rails being broken in one place and bent in others, fishes broken, etc.; while the sleepers were torn and split, one chair broken, and a crater about 12 feet in diameter opened.

Some of its other properties, such as its freedom from flame, the harmless nature claimed for its products of combustion, etc., were not tested.

In connection with these experiments, the claims of the inventor are given. M. Lamm claims for bellite the following advantages:

1. That it is one of the most powerful explosives known, being stronger than gun-cotton, gunpowder or dynamite.
2. That it possesses qualities of safety entirely foreign to explosive substances generally as follows: It presents no danger whatever in manufacture; it cannot be made to explode by friction, shock or pressure; it cannot be made to explode



by fire, lightning or electricity; it can only be made to explode by means of a detonating cap, and is therefore absolutely safe.

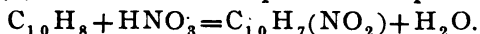
3. That upon being exploded, no noxious gases are given off, and therefore it is particularly adapted to blasting in mines, etc.
4. That bellite, made expressly for coal or rock blasting, does not shatter like dynamite, but detaches the material in large blocks with but a small percentage of dust.
5. That it does not undergo any chemical change from time nor atmospheric influences, always retaining its non-explosive character until the fulminating cap is applied to it.
6. That it can be used in shells that would prove of a terribly destructive character, and that such shells may be fired from guns of large calibre with the service charge of powder without risk to the piece.
7. That bellite can be safely manufactured in tropical climates, and transported by land or sea as ordinary merchandise.
8. That it requires no thawing, as it does not freeze or change its character in even the coldest weather; and
9. Finally, that it can be profitably manufactured and sold at a lower price than dynamite, or any other explosive possessing equal force.

**Securite.** This explosive is almost identical with bellite, differing only in the proportions of the ingredients when first introduced. Originally securite consisted of 74 per cent. of ammonium nitrate and 26 per cent. of meta-di-nitro-benzene. Recently, however, new varieties of this explosive have been introduced, which contain tri-nitro-benzene, and di- and tri-nitro-benzene. Also a variety known as *Flameless Securite*, made by adding ammonium oxalate to the varieties mentioned. Securite is a bright yellow granular substance which is said to be non-hygroscopic, and capable of being kept for any length of time without undergoing any change. It is insensitive to friction and percussion, cannot be exploded by a flame or incandescent body, requiring a detonating cap to provoke an explosion.

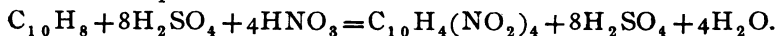
Its strength is said to be equal to that of dynamite No. 1.

**Volney's Powders.** In view of the attention which nitro-substitution compounds are receiving at present, it may be of interest to note the letters patent granted Mr. C. W. Volney in 1874,

His invention consists in mixing *nitrated naphthaline* with an oxidizing agent. By acting upon naphthaline with nitric acid of varying strength, substances are produced of corresponding degrees of nitration. Thus with nitric acid having the specific gravity of 1.40, the mono-nitro-naphthaline is produced :



While by using a mixture of strong sulphuric acid (sp. gr. 1.845) and nitric acid having a specific gravity of 1.50, we obtain the tetra-nitro-naphthaline :



All of the nitro-naphthalines will form explosive compounds when mixed with oxidizing agents which can supply sufficient oxygen to oxidize the surplus carbon; and it is evident that the higher the degree of nitration of the naphthaline, the less of the oxidizing agent will be required, while at the same time the greater will be the breaking power of the explosive.

Thus in order to make an explosive of moderate breaking power, which is therefore better adapted to military purposes, or blasting in soft and fissured rock, etc., the mono-nitro-naphthaline is used, being prepared commercially by incorporating

Naphthaline,	100 pounds,
Nitric acid (sp. gr. 1.40),	400 "

and leaving these substances in contact for four or five days, at the end of which time the naphthaline has been converted into a brown crystalline mass, which is thoroughly washed with water, dried and pulverized. This the inventor calls "Nitrated Naphthaline No. II."

The explosive made from this product is formed by mixing thoroughly

Nitrated Naphthaline No. II,	1.00 pound,
Saltpetre,	3.30 "
Sulphur,	0.51 "

These substances can be pulverized and mixed in the same manner as in the manufacture of ordinary gunpowder.

To prepare an explosive of great breaking power, such as would be adapted to filling torpedoes, submarine blasting, blasting of hard rock, etc., the tetra-nitro-naphthaline is used, which, prepared as follows, is called "Nitrated Naphthaline No. I." Commercially this nitro-compound is made by treating naphthaline with a mixture of two parts of strong nitro-sulphuric acid (sp. gr. 1.845) and one part of nitric acid (sp. gr. 1.50) at a temperature of 100° C., in the proportion of

Naphthaline,	100 pounds
Nitro-sulphuric acid,	400 "

At the end of one hour, the reaction is finished, all of the naphthaline having been converted into a bright yellow crystalline mass, which is washed, dried and pulverized as already indicated.

A very powerful explosive is made from this nitro-substitution product as follows :

Nitrated Naphthaline No. I,	2.18 pounds,
Saltpetre,	0.19 "
Sulphur	0.16 "

In both of these powders, any other nitrate or any chlorate may be substituted for saltpetre.

These powders are of a yellow color, and are unusually insensitive to friction, percussion, concussion and heat, and are therefore safely handled, stored, and transported. When unconfined except in the form of cartridges, they ignite and burn away harmlessly. It requires a powerful detonator, or a priming of gun-cotton, nitroglycerine, or dynamite, to develop their full power. Experiments in the Artillery School Laboratory show the relative strength of powders Nos. 1 and 2 to be respectively 58.44 and 53.18 as compared with standard nitroglycerine.

**Favier Explosives.** In his investigations looking to a reduction of the inherent dangers of nitroglycerine, M. Favier concluded that it was possible to make an explosive in which the nitrogen and carbon elements were simply placed in juxtaposition, but not combined. Acting upon this conclusion, he patented certain mixtures, which are known in Belgium as *Favier Powders*, but in England they are called *Ammonites*, and in other countries *Nitramites*.

According to his patents, M. Favier seeks "to replace explosive nitrogen compounds, like fulmicotton and nitroglycerine, in which the nitrogen compound and hydrocarbon elements are united in one definite compound, by simple mixtures of these same elements." He further proposes to use in the fabrication of his new powders substances which, under ordinary conditions, are absolutely stable, but which, by greatly increasing the initial detonation either by increasing the charge of fulminate in ordinary blasting caps, or by using an initial priming of gun-cotton or dynamite, could be fully detonated. These principles were applied in Belgium in 1887 to a mixture having the following composition :

Ammonium nitrate,	. . . . .	75 parts,
Resin,	. . . . .	5 "
Charcoal,	. . . . .	20 "

The mixture was forcibly compressed into a hollow cylinder, and the interior of this cylinder was filled with dynamite, which formed the initial detonator. It was found that, while a fulminate cap alone would not explode the compressed mixture, if the mixture were granulated, it could be detonated by 2 grammes of fulminate.

In his more recent powders, M. Favier has materially changed the compositions. The enveloping cartridge is made of ammonium nitrate and nitro-naphthaline "in the proportions necessary to produce a gas at the moment of oxidation." These proportions are approximately as follows :

Ammonium nitrate,	. . . . .	90 parts,
Nitro-naphthaline,	. . . . .	10 "

The nitro-naphthaline is melted and poured around the ammonium nitrate, which is thus enclosed for protection on account of its hygroscopic properties. Briefly described, the process of manufacture is as follows :

The nitrate is thoroughly dried by passing it slowly upon an Archimedian screw through a trough warmed by steam, and is then pressed into a warmed former and sprinkled with melted nitro-naphthaline. In this manner a homogeneous roll is formed

which passed next to the graining machine. When granulated, the grains are sifted, the smaller particles being reserved for intermediary detonators to be placed in the cartridge core, while the larger grains are molded warm into hollow cartridges, which are subsequently covered with paraffin, and after the detonator is inserted, the whole is enveloped in paraffin paper.

In France the government has secured control of these powders, and in the factory at Saint-Denis five varieties are made :

I.	Grisounite—Ammonium nitrate,	95.5 parts,
	Tri-nitro-naphthaline,	4.5 “
II.	Grisounite—Ammonium nitrate,	92.0 “
	Di-nitro-naphthaline,	8.0 “
III.	Poudre Favier No. 1—Ammonium nitrate,	87.5 parts,
	Di-nitro-naphthaline,	12.5 “
IV.	“ “ No. 2—Ammonium nitrate,	44.0 “
	Sodium nitrate,	40.0 “
	Di-nitro-naphthaline,	16.0 “
V.	“ “ No. 3—Sodium nitrate,	75.0 “
	Mono-nitro-naphthaline,	25.0 “

The ingredients used in these powders being very stable substances, they can be manipulated with great security, and their transport presents no danger. It is claimed for them that they are insensible to shock, fire and cold ; in fact their excess of stability is their only fault, as it requires one gramme of the fulminate of mercury to provoke detonation. On the other hand, the hygroscopic nature of ammonium nitrate, which forms so large a proportion of these powders requires great precaution in storage.

Of the varieties given above Poudre No. 3 seems to give the best results.

**Emmensite.** In January, 1888, letters-patent were granted to Dr. Stephen H. Emmens, of New York, for a new organic acid discovered by him, to which the name of *Emmens Acid* has been given, and the compounds formed with this acid bear the general name of Emmensite.

*Emmens acia* is obtained by dissolving commercial picric acid, at a gentle heat, in fuming nitric acid, (sp. gr. 1.50 to 1.55), and evaporating, when the new acid is deposited in rhomboidal prisms of a bright yellow color. According to Dr. Wurtz, this acid has

the formula of  $\text{H}_2\text{C}_6\text{H}_3(\text{NO}_2)_3\text{O}_2 \cdot \text{H}_2\text{O}$ , and may be regarded as being intermediate between tri-nitro-phenol and tri-nitro-cresol. This acid differs from picric acid in crystalline form; is less soluble in water and alcohol; gives off ruddy vapors when heated; and possesses a golden, rather than straw, yellow color.

Emmensite is prepared by fusing together in a paraffin bath

Emmens acid,	. . . . .	5 parts,
Ammonium nitrate,	. . . . .	5 parts,
(Or sodium nitrate,	. . . . .	5 parts,)

and finally incorporating

Picric acid,	. . . . .	6 parts.
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The grade of Emmensite recently tested at the U. S. Navy Yard, Washington, D. C., was composed of

Emmens acid,	. . . . .	1 part,
Ammonium nitrate,	. . . . .	1 part,
Sodium nitrate,	. . . . .	1 part,

and was made by the inventor as follows: The Emmens acid was placed in an earthen dish, and heated over a fire until it became semi-liquid. Then the nitrates were added gradually with constant stirring until the whole mass became a yellow paste, which, when taken from the fire and allowed to cool, hardened and assumed a crystalline appearance. This substance was then placed in a mortar and pulverized with a pestle.

Emmensite itself is manufactured in five different grades, while, with slightly and unimportant variations, it is known under other names. It has been proposed to use this explosive not only in mining, but also in a granulated form as a propelling agent as a substitute for gunpowder; for which purpose it is claimed to possess three times the force of gunpowder, while it produces no smoke, does not foul the piece, and is insensitive to shock or violent blows. These claims would seem to leave very little to be desired in a reliable service explosive, particularly as a further and all-important quality—that of stability during long storage—is also claimed. Elaborate calculations have been employed to determine the explosive force or strength of Emmensite as compared with other high explosives. Taking dynamite No. 1 as equivalent to 100, Emmensite is claimed to have a theoretical value of 236.60. This, however, is not verified practically, for in an



## LECTURE XII.

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### NITRIC ESTERS OR ETHERS.

**Nitric Esters or Ethers.** This class of explosive compounds has already been alluded to, and comprises all those explosives derived from the hydrocarbon groups by the action of nitric acid, in which *the nitrogen oxide is connected with the carbon atoms through the interposition of oxygen atoms.*

Two important and prominent examples of this class are gun-cotton and nitroglycerine, but like the several classes of explosives already mentioned, the list is capable of indefinite expansion.

**Gun-cotton.** Gun-cotton is, as its name implies, an explosive made from cotton. It is only necessary to immerse pure dry cotton in a mixture of the purest and strongest nitric and sulphuric acids to convert the cotton into gun-cotton.

The purification of the cotton, the conversion of the cotton into gun-cotton, and the purification of the gun-cotton are all somewhat difficult of attainment, and hence the manufacture involves some lengthy and rather complicated processes.

The necessity for these processes and their rationale can best be shown by reviewing the history of gun-cotton, for, in common with most of our modern processes, the present degree of attainment has been reached only through the labors and studies, the failures and successes of many investigators.

In 1832 Bracconot discovered that when starch, ligneous fibre and analogous substances were treated with concentrated nitric acid, a highly combustible body, which he termed xyloidine, resulted

Pelouze repeated these experiments in 1838 and extended his investigations to cotton and paper, which he held were best adapted for the production of this substance. He found that the body could be inflamed at 180° C. either by a blow or by a strong pressure, and he recommended its use in pyrotechny. Later,



Dumas prepared from paper, by this means, a substance which he called *nitramidine*, and which he proposed for use in making cartridges. The products thus obtained were, however, found to be irregular in composition and unstable, and so no practical result flowed from these researches, until late in 1845, when Schoenbein of Basle announced the discovery of an explosive, which he called gun-cotton, and which he claimed could be used for all the purposes for which gunpowder was used, while it was four times as powerful as the latter. He kept his method of manufacture secret, but in August, 1846, Boettger of Frankfort proclaimed his ability to make gun-cotton, and on conferring together it was found that the methods employed were the same, and hence the two formed a partnership for disposing of their secret to the German government, and the method remained unpublished.

However, on October 5th, 1846, Otto of Brunswick gave, in the *Augsburger Allgemeine Zeitung*, a description of a process for making a gun-cotton which closely resembled that of Schoenbein's, and which consisted in plunging purified cotton into very concentrated nitric acid for about one-half minute and then washing and drying with great care, while nearly at the same time (1847) W. Knop of Hanover and Taylor of England discovered that gun-cotton could be prepared by using mixtures of nitric and sulphuric acids.

These discoveries forced Schoenbein and Boettger to reveal their secret, and it was found that they too were using the mixed acids, the proportions being as follows:

	Sp. Gr.	Parts by weight.	Parts by volume.
Nitric acid, .	1.45 to 1.50	1	1
Sulphuric acid, .	1.85	3	2.3

The acids were mixed in a porcelain or glass vessel cooled to 10° or 15° C. Then the cotton was plunged in, the proportions being one part of cotton to from twenty to thirty of the acid. After about one hour the cotton was removed, washed in a large quantity of water, then in a solution of potash to remove the last traces of acid, and, finally, with pure water to remove the salts which had been formed. The material was then wrung out, impregnated with a weak solution of saltpetre, again wrung out, and finally dried at a temperature of 65° C.

Taylor's process differed only in using one part of cotton to fourteen of the mixed acids.

Heeren and Karmarsch used one part of fuming nitric acid to two of English sulphuric acid, while Knop used equal volumes of the two acids.

Both of these latter allowed the cotton to remain but from four to five minutes in the acid.

From this time, experiments were undertaken in the United States, Germany, France, England and Russia, to test the value of this explosive as a substitute for gunpowder in guns, but the material was found to be unstable and gave rise to several terrible, and at the time, inexplicable explosions at Vincennes, Bouchet and Faversham (1847-1848), which, combined with the grave political disturbances of the time, led to the discontinuance of the experiments, except in Austria, where Baron Von Lenk was engaged in its study.

**Von Lenk's Investigations.** From a consideration of all the attending circumstances Von Lenk concluded that the accidents above noted were due to the failure to purify the cotton perfectly; or to the use of too weak acids, or too short an immersion, so that the conversion was incomplete; or to the failure to remove the acids completely from the gun-cotton. The impurities which are present in cotton are of two kinds, natural and artificial. The natural consists of incrusting matter and oily matters. The artificial of oil and dirt generally, and water.

When impure cotton is immersed in the acid mixture, the incrusting substance and greasy matter are acted upon by the acids and form compounds which are quite unstable, and which, if present in the gun-cotton, may give rise to decomposition in the gun-cotton itself.

The moisture present serves both to dilute the acid mixture and to cause local heating during immersion, which causes waste of material and may give rise to the formation of unstable compounds which, if present in the gun-cotton, may also provoke spontaneous decomposition.

The use of weak acids or too short an immersion prevents the complete conversion of the cotton into the stable military gun-cotton. All chemical reactions require a certain time for their completion, and this is especially the case when the physical structure of either of the reacting bodies is such as to prevent rapid contact between them. The physical structure of cotton is such as to notably prevent the acids from rapidly coming in contact with its parts, for it consists of long, flat, twisted tubes which have been collapsed along their longitudinal axes, so that a cross section presents the form of a figure eight. It can readily be understood that a considerable time must elapse before the acid can penetrate completely into the interior of such a tube so as to convert all its substance into gun-cotton. For the same reason it will be understood that it must be very difficult to expel the last traces of acid from the capillary tubes, yet if any trace of acid remains in them, it is likely to provoke progressive decomposition in the gun-cotton.

**Von Lenk's Process.** This consisted in

1st. *The cleansing and perfect dessication of the cotton.*

The cleansing was effected by first removing the dirt and knots by mechanical means, then immersing the cotton in small portions, for two or three minutes, in a boiling solution of caustic potash (Sp. Gr. 1.021), in order to remove the fatty matters and incrusting substances, then removing the potash liquor by means of a centrifugal machine, and washing with pure water and finally drying at 95° F. At ordinary temperatures cotton wool exposed to the air absorbs 6 per cent. of moisture.

2d. *The employment of the strongest acids attainable in commerce.*

These consisted of nitric acid sp. gr. 1.48 to 1.49 at 17°.5 C. and sulphuric acid sp. gr. 1.835 mixed in the proportions of one part, by weight, of nitric to three parts, by weight, of sulphuric.

3d. *The steeping of the cotton in a fresh strong mixture of acids, after its first immersion and partial conversion into gun-cotton.*

A pot holding about 60 pounds of the acid mixture was used for the dipping, and two skeins (about 3 ounces) of cotton were dipped at each operation. After some minutes, the partially converted cotton was removed from the pot, placed upon a rack and squeezed until one part of the cotton contained about ten and one-half

parts of acid. The pressed cotton was now placed in a steeping pot and fresh acid poured over it, while the dipping pot was filled to its original level with acid.

4th. *The continuance of the steeping for twenty-four to forty-eight hours.*

After the gun-cotton had been placed in the steeping pot and the acid added, the gun-cotton was pressed to the bottom of the pot, so that it would be completely covered with the acid, the pot was then covered, placed in a trough of cool water and allowed to remain for the time stated.

5th. *The thorough purification of the gun-cotton, so produced. from every trace of free acid.*

To effect this the gun-cotton was placed in a centrifugal machine, revolving at about 800 turns per minute, and in about ten minutes the acid present was reduced so that about one pound of the gun-cotton contained but three pounds of acid.

The gun-cotton was then plunged into a cascade of water and washed in a running stream of water for from three to six weeks, and then treated with a weak solution of boiling potash, washed and dried in free air at 25° C. Then the gun-cotton was immersed for some time in a solution of sodium silicate (sp. gr. 1.072), wrung, and exposed for three days to free air, again washed, wrung and dried, first in free air, and finally in a chamber whose temperature did not exceed 35° C.

Von Lenk began the manufacture at Heitenberg, near Wiener-Neustadt, about 1853, and continued to direct the factory up to 1865, during which time considerable quantities of the material were made, and extensive experiments, on its value as a substitute for gunpowder as a projecting agent, were conducted with it, and the results were so favorable that the Austrians supplied thirty batteries with gun-cotton cartridges, and the explosive bid fair to soon be adopted as a service explosive, but, unfortunately, two serious explosions during storage occurred, one at the magazine at Simmering in 1862, and the other at the magazine of Steinfeld in 1865, and these combined with the fact that the explosive, in spite of the precautions taken, often developed abnormal pressures in the guns led to its use being interdicted.

**Abel's Improvements and Patents.** Von Lenk patented his process in England in 1862, and in 1864 the Prentice Brothers began the manufacture of gun-cotton under this process at Stowmarket.

In 1865 Abel patented his improvement on the process. This consisted in reducing the gun-cotton to a pulp, and then, by molding and pressure, converting it into such forms and masses as were desired for use. The pulping was effected by a rag engine or pulper, such as is used in converting the rags used in making paper into pulp.

The advantage gained by this is, *first*, that the gun-cotton tubes are cut into such short lengths that the acid and foreign matters can be easily and completely removed from the fibre; *second*, that cotton waste, a cheaper material, can be used for the manufacture; and *third*, since the pulped material can be pressed, it is possible to impart to the final product a high density and thus obtain a large weight of the explosive in a small volume.

Abel's modifications were shortly afterwards adopted at Stowmarket, and the manufacture and use were successfully pursued without accident until August, 1871, when 13½ tons of the compressed gun-cotton, which was stowed in the packing-house at Stowmarket exploded. A very thorough investigation of the circumstances attending this explosion was made, and, as a result, the jury found "that the accident was due to the spontaneous explosion of some impure gun-cotton, the impurity consisting in the presence of a large quantity of sulphuric acid, or of mixed sulphuric and nitric acids, which acids were wilfully added by some person or persons unknown, after the gun-cotton had passed through the regular process of manufacture and testing." Since then we have no record of any spontaneous explosions having occurred, and it is very unlikely that they should have taken place, for, thanks to Brown's discovery, the finished product is now almost wholly stored in the wet state. Shortly after the Stowmarket explosion the English government erected works at Waltham Abbey, and the French at Moulin-Blanc, and the other European governments followed suit, all of them adopting Von Lenk's process with Abel's modifications.

**Adoption of Gun-cotton in this Country as a Service Explosive.** As has been said above, experiments were made in this country, not long after the discovery of gun-cotton, to test its value as a projecting charge in guns, but they were soon abandoned, as the material was found to be too unsafe for use in this way.

Experiments were, however, begun at the U. S. Torpedo Station by Professor Hill in 1872 to test the value of the compressed gun-cotton, as made by Abel's process, for the use of the torpedo service, and the experiments were continued up to 1883, when on November 14 of that year a gun-cotton torpedo outfit was issued to the U. S. S. Trenton and the material was adopted as a service explosive.

The gun-cotton used in these experiments was obtained from Stowmarket, and that issued to the Trenton was in the form of cylindrical discs three inches in diameter and two inches high.

Having been adopted as a service explosive, it was not deemed prudent to depend upon foreign sources for our supply, so a plant for its manufacture was extemporized at U. S. N. Torpedo Station, which was set in operation in March, 1884, and has been continued ever since, manufacturing gun-cotton as the needs of the Navy have required, so that, to-day, every ship in commission is supplied with her proper outfit, and we have stored in our magazines sufficient material to meet any immediate demands.

**Chemistry of Gun-cotton.** We will now consider the chemistry of gun-cotton. This body, like the compounds referred to in the lecture on the picrates, is composed of carbon, hydrogen, oxygen and nitrogen, but it differs from them in the fact that while they are nitro-substitution compounds, this is a true salt and belongs to the class of organic salts known as esters. It may be designated as cellulose nitrate, and the pure cotton fibre from which it is made is chemically known as cellulose. Owing to the fact that the cellulose is a non-volatile solid, its vapor density has never been determined, and so its molecular weight, and hence its molecular constitution is unknown.

Its ultimate analysis leads to the simplest empirical formula of  $C_6H_{10}O_5$ , but it is probable that its molecular constitution will be truly represented by some multiple of this expression.

From its reactions cellulose may be regarded as a tribasic alcohol, the formula then being  $C_6H_7O_2(OH)_3$ .

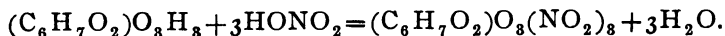
Cellulose forms the principal ingredient of the cell membranes of all plants, so that it may be obtained from any of the multitude of existing plants, but the incrusting and other substances associated with the cellulose, as is readily seen by inspection, vary much with the plant in which it exists, so that while wood sawdust and a variety of similar substances have been and are employed for the manufacture of cellulose nitrates, cotton has been found to be the source from which we could most easily and readily obtain an abundant supply of nearly pure cellulose.

The purest cellulose which we meet with, however, is probably found in the so-called Swedish paper, which is employed in chemical laboratories for the purpose of filtration.

When cellulose is acted upon by nitric acid or mixtures of nitric and sulphuric acids, the hydrogen of the hydroxyl is replaced, more or less completely, by  $NO_2$ , and in this way various cellulose nitrates may be obtained. The composition of the products resulting from this action depends upon the strength of the acids employed, the proportions of acid used, the temperature during immersion, and the time of immersion. If the acids are as follows:

	Sp. Gr.	Parts by weight.
$HNO_3$ , . . . . .	1.50	1
$H_2SO_4$ , . . . . .	1.85	3

the proportions of cellulose to acid is as 1 : 300, the time of immersion ten minutes, the time of steeping forty-eight hours, and the temperature about  $15^\circ C.$ , then we ought to obtain the most complete conversion of the cellulose, and the reaction would be represented as follows:



The cellulose nitrate so obtained is familiarly known as the "*tri-nitro-cellulose*," and, according to Abel, it is the principal constituent of the military gun-cotton.

By the action of weaker acids, or other changes in the qualifying conditions, cellulose nitrates, in which less of the hydroxyl hydrogen is replaced, are obtained, and they are generally represented by the formula  $(C_6H_7O_2)O_3(NO_2)_2H$  and  $(C_6H_7O_2)O_3(NO_2)H_2$ , the bodies being called "*di-nitro-cellulose*" and "*mono-nitro-cellulose*" respectively, and it is claimed that these lower compounds may be readily distinguished from the higher by the action of solvents upon them, the lower compounds being soluble in a mixture of common ether and alcohol, while the "*tri-nitro-cellulose*" is insoluble in this mixture.

From the difficulty attending the study of non-volatile bodies like cellulose and its esters, it is to be expected that differences of opinion will exist regarding their exact constitutions, hence we are not surprised to find that Vieille, from his researches, holds them to be more complex than they have, following Abel, been represented above. Vieille regards cellulose as having the composition  $C_{24}H_{40}O_{20}$ , and by acting upon it with a mixture of the strongest nitric and sulphuric acids at  $11^\circ C.$ , the cotton being to the acids as 1:100, or 150 by weight, he obtained  $C_{24}H_{28}O_{20}(NO_2)_{11}$ , called the "*endecanitate*," and which is completely soluble in ethyl acetate (acetic ether). Nitric acid (sp. gr. 1.502) alone gave  $C_{24}H_{30}O_{20}(NO_2)_{10}$ , the "*decanitate*," which was completely soluble in ethyl acetate and slightly soluble in ether-alcohol solution. With weaker acids he obtained successively  $C_{24}H_{31}O_{20}(NO_2)_9$  the "*nono-nitrate*," and  $C_{24}H_{32}O_{20}(NO_2)_8$  the "*octonitrate*," both of which were soluble in ethyl acetate and in ether-alcohol; the  $C_{24}H_{33}O_{20}(NO_2)_7$ , the "*heptanitate*," which gelatinized, without true solution, in ethyl acetate and ether-alcohol; the  $C_{24}H_{34}O_{20}(NO_2)_6$ , the "*hexanitate*," which swelled up in ethyl acetate without dissolving, and which was unacted upon by ether-alcohol; and, finally, the  $C_{24}H_{35}O_{20}(NO_2)_5$  and  $C_{24}H_{36}O_{20}(NO_2)_4$ , the "*penta*-" and "*tetranitrates*," which were obtained as friable pastes and were unacted upon by either the ethyl acetate or ether-alcohol.

As has been said, the "*tri-nitro-cellulose*" of Abel, or the *en-deca*- and *decanitrates* of Vieille, are gun-cotton, the other cellulose nitrates being known as pyroxylin, and those of them which are soluble in ether-alcohol as collodion gun-cotton. These latter



are called collodion gun-cotton from the fact that the solution which they form with ether-alcohol, when exposed to the air, gives up its ether and alcohol by volatilization and deposits its gun-cotton as a gummy, colloidal, strongly adhesive film on the body with which it is in contact. This solution, known as collodion, is employed for coating the surfaces of the plates used in the wet process of photography, and it is also used in surgery to produce an artificial skin over cuts and wounds.

**Properties of Gun-cotton.** The fibrous gun-cotton seen in ordinary light differs little, if any, in appearance, even when examined under a microscope, from the cotton from which it is made, but, if seen under the microscope by polarized light, the fibres of gun-cotton appear dull and only feebly colored, while cotton fibres, under the same circumstances, are brilliant in lustre and iridescent.

Gun-cotton is harsher to the touch and less flexible than cotton; when dry it becomes quite highly electrified if rubbed between the fingers, and is luminous when rubbed in the dark.

Gun-cotton is completely insoluble in water either hot or cold.

The action of ethyl acetate and of ether-alcohol upon it and the pyroxylin has been noted above.

Gun-cotton is also soluble in a mixture of ether and ammonia and in acetone ( $(\text{CH}_3)_2\text{CO}$ ). All the cellulose nitrates are soluble in a strong solution of sodium hydroxide, undergoing a partial saponification, with the formation of cellulose and sodium nitrate. Concentrated sulphuric acid displaces the nitric acid even in the cold. Reducing agents, such as ferrous chloride or acetate, or the alkaline sulphyroxides, especially in alcoholic solution, convert the cellulose nitrates into cellulose, even by digestion at ordinary temperatures. By boiling with a solution of stannous oxide in potassium hydroxide the cellulose nitrates are dissolved and the cellulose is reduced and may be precipitated in flocks on neutralizing the liquid. These reactions are often employed in the analysis of the cellulose nitrates. The density of gun-cotton varies with the mode of preparation and the amount of compression to which it is subjected. It averages about 0.1 to 0.3 for gun-cotton in the form of flocks or fibre, and is about 1.1 for the dry compressed Abel gun-cotton. Experiments made at

L'Ecole de Pyrotechnie de Toulon (1870) showed that the pressure to be applied increases much more rapidly than the density of the resulting product, and that it is impracticable to carry the density above 1.4 to 1.5.

Gun-cotton is said to be less hygroscopic than either ordinary cotton or than gunpowder. The normal humidity of air-dry gun-cotton is put at 1.5 to 2 per cent., though it is believed that by prolonged exposure to a saturated atmosphere it may reach 2.75 per cent., but this does not appear to have any marked effect on its inflammability. According to Beckerhinn an increase in the percentage of moisture in gun-cotton used for projecting charges causes a more rapid fall in the pressure produced than in the initial velocities given, which, if true, gives a means for neutralizing the brisant effect of gun-cotton on the piece, while leaving us a ballistic medium much superior in power to ordinary gunpowder.

It is claimed that gun-cotton is not susceptible, even when dry, to pressure, percussion or friction, unless it be strongly confined and firmly compressed, and the heat developed is very considerable, but experiments in this laboratory tend to disprove this claim.

To explode dry gun-cotton, by percussion, with some degree of certainty, it is necessary to take a very small piece, wrap it tightly in tinfoil, place it on an anvil, strike it several light blows to compress it, and then a heavy blow. If the latter is not fair it will fail to effect the result. As will be seen later, shell filled with discs of dry gun-cotton have been fired from 24-pounders with service charges of powder into the masonry escarpment of the fort on Rose Island at a distance of 50 yards from the muzzle of the gun, where the shell were completely broken up on impact without any of the gun-cotton having been exploded.

The wet gun-cotton is in the process of pressing subjected to a pressure of about 6,300 pounds per square inch; and the pressure has been carried to over 13,000 pounds without causing explosion.

If a flame or any incandescent body is applied to dry loose gun-cotton, the latter burns with a flash but without explosion. If the gun-cotton is woven or twisted tightly, the speed of combustion is very much reduced, and when the gun-cotton is pulped

and compressed, the rate of combustion is reduced still more. If water is poured on a disc or block of burning gun-cotton, the flame may be extinguished, though sometimes, when the fire is inside, it can be reached only with difficulty.

If the mass of burning gun-cotton is very large, it is possible that an explosion may take place from the outer parts furnishing sufficient confinement to the inner.

Wet compressed gun-cotton cannot be set on fire until the moisture is dried out of it. If a wet disc or block be placed in a fire, the outer surface will dry and be slowly consumed, and this will continue, layer by layer, until the whole is consumed. It is a common experiment at the U. S. Naval Torpedo Station to place a magazine box filled with wet gun-cotton in a fierce bonfire and let it burn away, taking out some of the burning discs and extinguishing them by rolling on the ground or plunging in water, and subsequently exploding them by detonation. As much as 2,000 pounds of wet gun-cotton has been placed in a bonfire, where it slowly burned away without explosion. The point of explosion of gun-cotton and pyroxylin naturally vary somewhat, but that of gun-cotton may be taken as about  $182^{\circ}$  C. ( $360^{\circ}$  F.)

The Stowmarket test required that it should be above  $172^{\circ}$  C.

Considerable apprehension exists in the minds of many, who are not intimately acquainted with the substance, regarding gun-cotton, and they are apt to fear that, through decomposition during storage transportation, or by the action of ordinary shocks, heat or pressure, it may accidentally explode.

These apprehensions have arisen from the many accidents which have occurred in the history of the explosive, some of which have been noticed already, and which, as has been pointed out, were due to the impurities existing in the gun-cotton as a necessary result of the imperfect processes of manufacture followed, and these apprehensions are strengthened by the many accidents which have occurred in the past and still do occur with other high explosives, and which many appear to think is a necessary consequence of their use.

While gun-cotton is a powerful explosive, and in fact a high explosive, and necessarily dangerous as all explosives must be, yet, when handled, used and stored as directed, it is the safest explosive known, and when in the condition in which it is issued from the U. S. Naval Torpedo Station, it is wholly free from any tendency to undergo a dangerous decomposition. Partly owing to this fear which has existed, and partly owing to the nature of the instructions given, there have been several instances reported where gun-cotton has been condemned and thrown overboard.

In the majority of these cases, samples of the condemned gun-cotton have been secured from the same lots as those to which the condemned gun-cotton belonged, and no indication whatever of dangerous decomposition has been discovered.

**Decomposition of Gun-cotton.** When gun-cotton is decomposing, it first begins to give off nitrous fumes and eventually yields them in such quantity as to color the surrounding atmosphere a deep brownish-red. At the same time the gun-cotton begins to show pasty yellow spots, and eventually the whole becomes converted into a pasty yellow mass which first shrinks to about one-tenth of the volume of the original gun-cotton and then swells up as the gas is evolved. Next the mass shrinks again and becomes converted into a gummy residue having a very much smaller volume than the gun-cotton from which it was formed, and finally it dries up to a brown horn-like mass.

This decomposition results in the formation from the gun-cotton of oxides of nitrogen, formic and acetic acids which are evolved as vapors, and an amorphous, porous, sugar-like body almost entirely soluble in water, which contains a considerable quantity of glucose, gummy matter and oxalic acid, and a small quantity of formic acid, and of pectic and para and meta-pectic acids. Changes such as these just described have repeatedly taken place under my own observation with gun-cotton which has been imperfectly freed from acid, or with pyroxylin, and many other chemists have observed them, and in none of these cases did an explosion, or anything approaching an explosion, take place.

The decomposing effects of acids may also be witnessed at the U. S. Naval Torpedo Station on any Saturday while the gun-cotton factory is in operation, for it is the custom at that time to take

the waste sweepings of the factory, which have accumulated during the week, to the beach, and to pour upon them a quantity of the waste acid mixture.

Soon after the acid is poured on, the mass begins to yield copious quantities of oxides of nitrogen (or, as the workmen technically say, "firing" takes place) and the mass undergoes the changes described above, but no explosion ensues. These observations have been made on gun-cotton decomposing when unconfined or when loosely confined. It is of course obvious that if the gun-cotton was confined in a tight receptacle the gases evolved during decomposition might generate pressure enough to burst the receptacle and thus produce an explosion.

Again, as heat is produced by the chemical reaction, it might be possible that, when the gun-cotton is confined, the heat generated cannot be conveyed away as fast as generated, and that in consequence, the temperature continually increases so that it eventually reaches the ignition point of the explosive, then, of course, an explosion might ensue, and this is the probable explanation of the origin of the explosions noted as occurring in the magazines at Stowmarket and elsewhere. The decompositions described have, with the exception of the destruction of the waste at this station, been observed to take place only in dry gun-cotton or pyroxylin.

To produce it in wet gun-cotton it is necessary that the amount of acid present should be very much in excess of the gun-cotton with which it is in contact, hence the development of such slight traces of acid during the storage of wet compressed gun-cotton, as have been observed by Abel, is not likely to produce dangerous decomposition, while besides the water present tends to prevent any considerable rise in temperature.

It is well known that light rays sometimes play an important part in inducing chemical changes. We have only to cite the well-known cases of the decomposition of carbon dioxide within the leaf-cells of plants, or of the silver salts in the photographic plate, or better, in this connection, the decomposition of the

amides. It is not to be wondered at that it should be believed and expected that gun-cotton would also be susceptible to the action of light, especially since Tyndall has shown that nitrous esters like the amyl and butyl nitrites may be decomposed by the action of a beam of light. The literature of gun-cotton and pyroxylin is full of the most conflicting statements regarding the effect of light upon them, but this is not surprising when we consider the great variety of substances employed and their varying degrees of purity as made by different methods. The most searching and exhaustive examination of this question has probably been made by Abel, and we quote his conclusions. Gun-cotton produced from properly purified cotton, according to the directions given by Von Lenk, may be exposed to diffused daylight, either in open air or in closed vessels, for very long periods without undergoing any change.

The preservation of the material for three and one-half years under these conditions has been perfect. Long-continued exposure of the substance, in a condition of ordinary dryness, to strong daylight and sunlight produces a very gradual change in gun-cotton of the description defined above; and the statements which have been published regarding the very rapid decomposition of gun-cotton when exposed to sunlight do not therefore apply to the nearly pure cellulose nitrate obtained by strictly following the system of manufacture now adopted. If gun-cotton in closed vessels is left for protracted periods exposed to strong daylight and sunlight in a moist or damp condition, it is affected to a somewhat greater extent; but, even under these circumstances, the change produced in the gun-cotton by several months exposure, is of a very trifling nature.

Singularly enough it has been found that gun-cotton, which had been freely exposed to air and diffused sunlight for about twelve months, had its stability, as determined by the heat test, very materially raised. Gun-cotton which is exposed to sunlight until a faint acid reaction has become developed, and is then immediately afterwards packed in boxes which are tightly closed, does not undergo any change during subsequent preservation in ordinary storehouses (as far as an experience of three and one-half

years has shown.) Gun-cotton prepared and purified according to the prescribed system and stored in the ordinary dry condition, does not furnish any indication of alteration beyond the development, shortly after it is first packed, of a slight peculiar odor, and the power of gradually imparting to litmus, when packed with it, a pink tinge.

Abel has also studied the effects of heat upon both dry and wet gun-cotton, and he finds that the influence exerted upon the stability of gun-cotton of average quality, as obtained by strict adherence to Von Lenk's system of manufacture, by prolonged exposure to temperatures considerably exceeding those which are experienced in tropical climates, is very trifling, and it may be so perfectly counteracted by very simple means, which in no way interfere with the essential qualities of the material, that the storage and transportation of gun-cotton presents no greater danger, and is, under some circumstances, attended with much less risk of accident, than is the case with gunpowder. Perfectly pure gun-cotton resists to a remarkable extent the destructive effects of temperatures, even approaching  $100^{\circ}$  C., and the lower cellulose nitrates (soluble gun-cotton or pyroxylin) are at any rate not more prone to alteration, when pure. The incomplete conversion of cotton into the most explosive product does not, therefore, of necessity result in the production of a less perfectly permanent compound than that obtained by the most perfect action of the acid mixture.

But all ordinary products of manufacture contain small proportions of organic nitrogenized impurities, of comparatively unstable properties, which have been formed by the action of nitric acid upon foreign matters retained by the cotton fibre, and which are not completely separated by the ordinary, or even a more searching process of purification.

It is the presence of this class of impurity in gun-cotton which first give rise to the development of free acid, when the substance is exposed to the action of heat; and it is the acid thus generated which eventually exerts a destructive action upon the cellulose products, and thus establishes decomposition which heat materially accelerates. If the small quantity of acid developed from

the impurity in question be neutralized as it becomes nascent, no injurious action upon the gun-cotton results, and the great promoting cause of the decomposition of gun-cotton by heat is removed.

This result is readily attained by uniformly distributing through gun-cotton a small proportion of a carbonate; the sodium carbonate, applied in the form of a solution, being best adapted to this purpose. The introduction into finished gun-cotton of one per cent. of sodium carbonate affords to the material the power of resisting any serious change, even when exposed to such elevated temperatures as would induce some decomposition in the perfectly pure cellulose products. That proportion affords, therefore, security to gun-cotton against any destructive effects of the highest temperatures to which it is likely to be exposed, even under very exceptional climatic conditions. The only influences which the addition of that amount of carbonate to gun-cotton might exert upon its properties as an explosive, would consist of a trifling addition to the small amount of smoke attending its combustion, and in a slight retardation of its explosion, neither of which could be regarded as results detrimental to the probable value of the material.

It has been observed that when dry gun-cotton is freely exposed to air in an atmosphere of a temperature of about  $45^{\circ}$  C. for about three months, its stability, as determined by the heat, is materially raised just as Abel found it to be for exposure to diffused daylight.

Water acts as a most perfect protection to gun-cotton (except when it is exposed to sunlight) even under extremely severe conditions of exposure to heat. An atmosphere saturated with aqueous vapor suffices to protect it from change at elevated temperatures, and wet or damp gun-cotton may be exposed for long periods in confined spaces at  $100^{\circ}$  C. without sustaining any change. Actual immersion in water is not necessary for the most perfect preservation of gun-cotton; the material, if only damp to the touch, sustains not the slightest change even if closely packed in large quantities. The organic impurities, which doubtless give rise to the very slight development of acid when gun-cotton is closely packed in the dry condition, appear equally protected by



the water; for damp and wet gun-cotton which has been preserved for three years has not exhibited the faintest acidity. If as much water as possible be expelled from the gun-cotton by the centrifugal extractor, it is obtained in a condition in which, though only damp to the touch, it is perfectly non-explosive; the water thus left in the material is sufficient, not only to act as a perfect protective, but also to guard against all risk of accident.

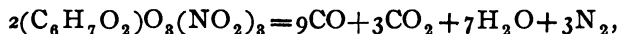
It is therefore in this wet condition that all reserve stores of the substance should be preserved, or that it should be transported in large quantities. If the proper proportion of sodium carbonate be dissolved in the water with which the gun-cotton is originally saturated for the purpose of obtaining it in this non-explosive form, the material, whenever it is dried for conversion into cartridges, or employment in other ways, will contain the alkaline matter required for its safe storage and use in the dry condition in all climates. Cold has no effect upon dry gun-cotton, but, of course, if low enough, it may freeze the water in the wet gun-cotton, and when the latter is in the form of compressed pulp, as now issued, the freezing will cause flaking, cracking and breaking down of the physical structure with a consequent reduction in density, hence freezing is to be avoided if possible. Alternate changes from heat to cold and the reverse, unless excessive, have little effect on the physical structure and none on the chemical stability of gun-cotton.

**Explosive Effect of Gun-cotton.** From what has been said with respect to the products of explosion of gunpowder, it might be expected that those furnished by gun-cotton would vary according to the conditions under which the explosion takes place. When a mass of the gun-cotton wool is exploded in an unconfined state, the explosion is comparatively slow (though appearing to the eye almost instantaneous) since each particle is fired by the flame of that immediately adjoining it, the heated gas (or flame) escaping outwards, so that some time elapses before the interior of the mass is ignited. But when the gun-cotton is enclosed in a strong case, so that the flame from the portion first ignited is unable to escape outwards, and must spread into the interior of the mass, this is ignited simultaneously at a great number of points, and the decomposition takes place far more rapidly; a given weight

of gun-cotton being thus consumed in a much shorter time, a far higher temperature is produced, and the ultimate results of the explosion are much less complex, as would be expected from the well-known simplifying effect of high temperatures on chemical compounds.

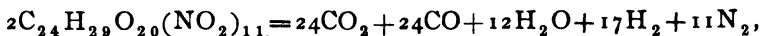
The determination of the products of explosion of confined gun-cotton was effected by Karolyi by enclosing the gun-cotton in a cast-iron cylinder, strong enough to resist bursting, until the combustion of the last portion of the charge (which was suspended in an iron globe exhausted of air, and exploded by a galvanic battery,) was complete; the total volume of the resulting gases was then measured and subjected to analysis.

Unfortunately, the cellulose nitrate used by Karolyi was not pure gun-cotton, so his results are but roughly approximate, still they indicate that the reaction might proceed according to the following equation:



although, naturally, no single equation would be likely to represent the complex reactions involved in an explosion by ignition. From this equation we deduce that one gram of gun-cotton yields 829 c. c. of gas at  $0^\circ$  and 76 cm., or, with one cubic centimeter of compressed gun-cotton having a density of unity, one volume of this gun-cotton would yield 829 volumes of gas.

The quantity of heat generated in the explosion of gun-cotton, according to Roux and Sarrau, is 1,056.3 centigrade units. The specific heat of the products of explosion is 0.2855, and this gives the temperature of the gas at the moment of explosion as  $3,700^\circ\text{C}$ . At this temperature the 829 volumes become expanded to 12,064, exerting a pressure of 81 tons per square inch if the density of gun-cotton is 1. The experiments of Noble and Abel have indicated  $4,400^\circ\text{C}$ . as the temperature of explosion, and a pressure considerably more than double that produced by gun-powder when fired in a space which is entirely filled by the charge. Sarrau and Vieille found that at the high pressures the water was dissociated, more of the carbon dioxide being formed. Using Vieille's formula this may be represented by the equation



and by calculation we find that the initial pressure exerted by gun-cotton is over three times that of gunpowder, and that, like that of gunpowder, the effect is reduced in practice by the incomplete state of combination of the elements and the complexity of the products which they tend to form, and the result is that the impact becomes less brusque and more regular as the combination becomes more complete during cooling. The value of gun-cotton as a military explosive was much enhanced by the discovery, made in 1868 by E. O. Brown of the Chemical Department at Woolwich, that it could be detonated, even when unconfined, by means of a small charge of mercury fulminate, and that it could even be so detonated when thoroughly saturated with water, if only a small initial charge of dry gun-cotton be detonated in contact with it, and this is the method which is now universally used for producing the explosion of compressed gun-cotton, for not only is it easy of application and enables us to explode gun-cotton when wet, but causes the explosive to develop the maximum force in a very small interval of time, and thus to produce that crushing effect which is desirable in a torpedo explosive. Berthelot estimates the pressure produced by the detonation of gun-cotton of density 1.1, when in contact, to be 24,000 atmospheres, or about 160 tons to the square inch, which is one-half the pressure estimated for mercury fulminate.

Sebert finds the rate of propagation of the detonation, when the gun-cotton is confined in tubes of tin, to be from 5,000 to 6,000 meters per second, while it is but 4,000 in tubes of lead. Piobert found the rate of inflammation in flocculent gun-cotton in free air to be eight times that of gunpowder.

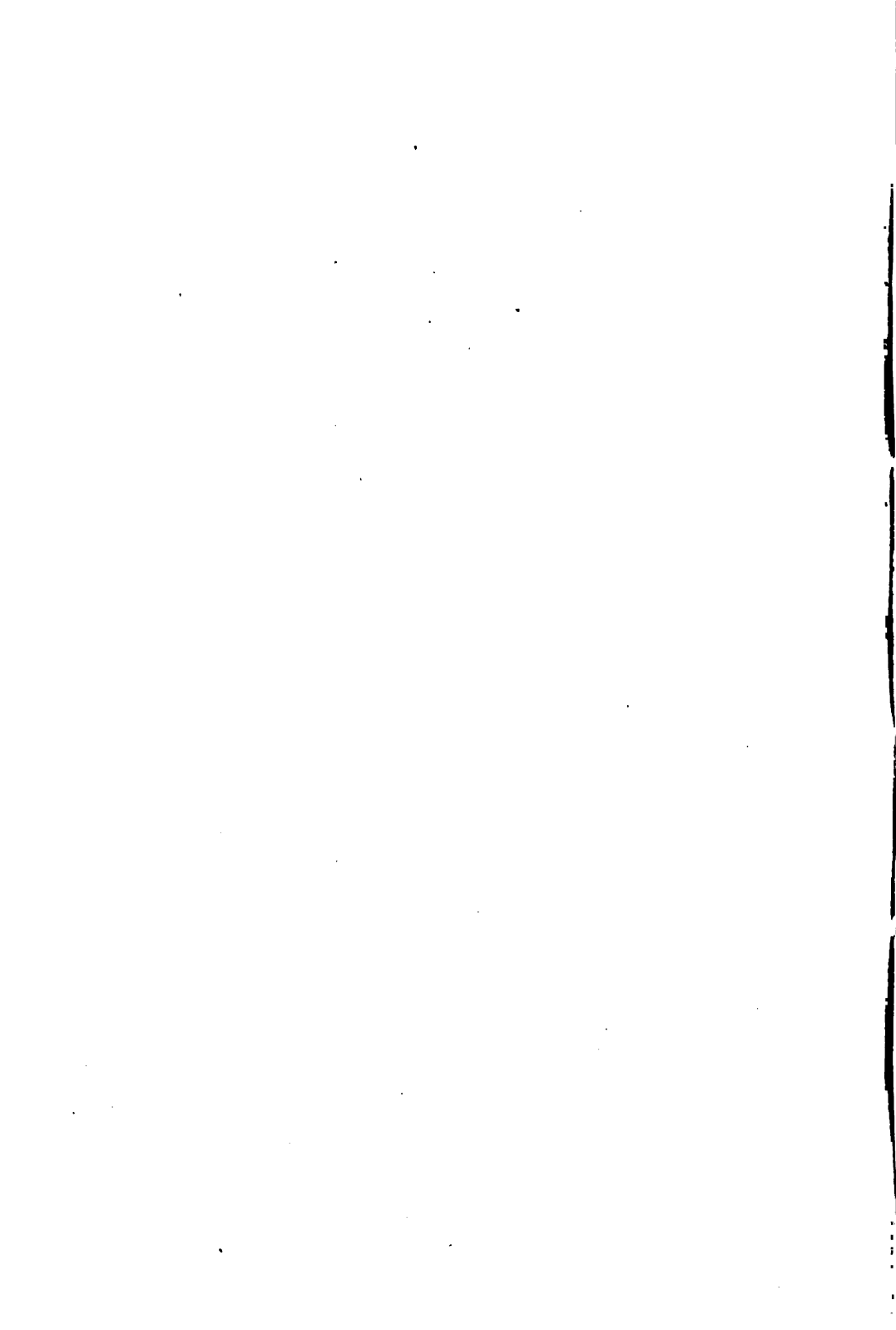
The results of experiment show that thoroughly dry gun-cotton may be detonated by three grains of mercury fulminate, and air-dried gun-cotton by five grains, provided the fulminate is well confined in copper cases, and the cases are in intimate contact with the gun-cotton.

These conditions are important to success. Notwithstanding so small a quantity can effect the detonation, thirty-five grains of the fulminate are used in the U. S. Navy detonators which are

used with the naval torpedo system.

When gun-cotton, or any other high explosive, is tamped, we obtain a more violent disruptive effect, through its detonation, than when it is untamped, for confinement brings about the most complete decomposition. When freely exposed to the air, gun-cotton is supposed to be untamped, but this is not strictly true with this or any other high explosive, for it acts so quickly as to violently disturb and set in motion a very considerable mass of the atmosphere, and this atmosphere acts as a tamp.

Wet gun-cotton appears to be a more violent disruptive agent when detonated than dry gun-cotton, and this notwithstanding that its combustion is not so complete. This fact has been explained by supposing that the water in its pores being nearly incompressible and highly elastic, increases the rate of propagation of the explosive reaction, and hence diminishes the time factor.



## LECTURE XIII,

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### MANUFACTURE OF GUN-COTTON AT THE U. S. NAVAL TORPEDO STATION.

The cotton used at this station is the kind known as "weaver's" or "cop" waste. It is the tangled clippings from the spinning room, and is received in bales containing about 500 pounds each. This form of cotton is preferred to cotton "wool" on the ground that the thready form prevents the material from packing closely together when wet by the alkaline solutions, water or acids used in the various processes through which it is passed, and thus permits of more complete, uniform and speedy treatment, while it diminishes the chances of fuming during "dipping." Besides the original cost of the waste is less than that of cotton of a marketable length. The waste as received contains knots, "cops," (small bits of paper upon which the thread is wound,) dirt and oil from the machines, together with incrusting substances, naturally existing on the fibres, and hygroscopic moisture, all of which must be removed before the material is subjected to the nitrating process. Hence the first step is the manual sorting of the waste to remove the larger foreign bodies such as nails, pebbles, bits of wood, metal and paper, which are sometimes found in it, and then the waste passes to the

**First Boiling-Tub.** This is a covered tub which is heated by live steam. The tub is made of white pine and has a capacity of 500 gallons. Two hundred (200) pounds of cotton are placed in the tub to which 250 gallons of water and 35 pounds of caustic soda are added, the steam is turned on, and the whole maintained at the boiling point for eight hours. The liquid is then drained off from the cotton, which remains thus over night when the tub is filled with clear water and the boiling continued for eight hours more and again drained over night. By the manual picking the larger masses of foreign bodies have been removed. By the boiling with alkali the oils are saponified, and the soap formed acts

as a detergent and removes much of the dirt, while the boiling alkaline solution acts also as a solvent for the incrusting matter. This process affects the fibre, for by prolonging the boiling with the alkaline solution or increasing the amount of alkali the fibre is materially weakened, and advantage may be taken of this to facilitate the operation of pulping, but the gain in this direction does not compensate for the loss in the product, while the hot, strong alkali solution rapidly destroys the tub.

From the first boiling-tub the wet cotton passes to the

**First Centrifugal Washer.** This is a machine of the ordinary form and construction, being 26 inches in diameter,  $\frac{1}{4}$ -inch mesh, and making about 1,400 revolutions per minute. From 6 to 7 pounds of the cotton are put in the centrifugal at a charge, the wringer is set in revolution and a stream of fresh water is turned on the cotton and allowed to play upon it until the slippery feeling (due to the alkali) has disappeared. This operation requires about 8 minutes, and the washing of the whole charge from the boiling-tub requires two hours. From here the cotton passes to the

**First Drying Room.** This is a room 5 feet 10 inches by 11 feet 4 inches and 11 feet high, the walls and ceilings of which are sheathed with asbestos paper. Around two sides of this room are nine rows of shelves or racks made of galvanized iron wire netting 1 to  $\frac{1}{2}$  inch mesh. Hot air enters the room from the final drier through a flue in one side and near the floor, which, after passing about and through the cotton on the shelves, issues by a ventilating flue at the top of the room. By the aid of the hot air the temperature of this drying room is maintained at a temperature about 187° F.

The cotton from the wringer is spread on the shelves in a layer about 2 to 4 inches thick, and it remains in this room, being turned every day, after the second day, until it is perfectly dry to the touch. The time for drying varies from three to five days.

From the drying room the cotton passes to the

**Picker.** This is the ordinary machine used in cotton mills, and consists of an endless flexible table upon which the cotton is fed, two small horizontal cylinders, armed with teeth, rotating in opposite directions, and a large wooden drum which is also armed

with teeth. As has been said, the cotton waste, as received, is badly tangled and contains many knots and rolls. It can be readily understood that the stirring and boiling, produced by the live steam in the boiling-tub, tends to tangle the mass still more. The complete conversion of the cellulose depends to a large degree upon the form of the cotton when it goes into the acid. If knots and rolls be present in the cotton they produce more or less "firing," and they are more or less yellow after the conversion. The picker serves to straighten out the tangled mass and open up the knots and rolls, so that the acid may have ready access to the fibre, but the cylinders of the picker should be so adjusted that the thread is not torn apart by this process. It takes about two hours to pass 200 pounds of cotton through the picker, and it results in about three pounds of loss. The cotton passes from the picker to the

**Final Drying Closet.** This consists of a large closet 6 feet  $7\frac{1}{2}$  inches long, 4 feet wide, and 5 feet  $4\frac{1}{2}$  inches high, made of galvanized iron, which contains two sets of six drawers, each 2 feet wide, 3 feet 10 inches long, and 4 inches deep, made of the same material, with the exception of the bottoms, which are made of galvanized iron wire netting of  $\frac{1}{2}$  to 1 inch mesh. These drawers are 5 inches apart vertically with a sheet of  $\frac{1}{4}$ -inch galvanized iron between them which serves to deflect the current of heated air. Air, which has been drawn over a steam radiator, is driven into this closet by means of a No. 4 Sturtevant blower, and led about and through the cotton out of the drying room. By means of this hot air the temperature of the closet is maintained at about  $225^{\circ}$  F., but has varied from  $200^{\circ}$  to  $260^{\circ}$  F. The cotton from the picker, which contains from 6 to 10 per cent. of moisture, as all atmospherically dry cotton does, is spread over the drawers in a layer about 4 inches thick, and the drawers are then closed. The cotton is allowed to remain in the drying closet for eight hours, at the end of which time it is estimated to contain from .25 to .50 per cent. of moisture. *One-half of one per cent. is the largest amount of moisture which the cotton may contain at the time of dipping.* With a large amount, even if it only reaches to one per cent., a reaction takes place by which unstable compounds are formed which are not removed by the subsequent treatment which



the gun-cotton undergoes. It is stated that an amount of moisture which is seriously objectionable, when present in the cotton at the time of dipping it in the acids, may be present in the acids in which the cotton is dipped without material harm to the process or product. In order that the highest nitric ester may be obtained, it is essential that the cotton at the time of dipping should be pure, dry and cool. Hence, in order to cool it out of contact with the air, it is packed directly from the drawers of the final drying closet, and, while yet hot, into service powder tanks, the covers of which are screwed on air-tight, and then the whole is allowed to stand in a cool room over night. The 150-pound powder tank holds about ten pounds of cotton when filled by hand pressure. The tanks containing the cool cotton are then transported by tram cars running through the factory to the

**Dipping or Converting Room.** This room contains the dipping troughs, acid reservoirs, digestion pots and cooling troughs.

**Dipping Troughs.** Five of these, each having a capacity for about 150 pounds of mixed acids, are used. They are made of cast iron, and are set in an iron trough in which cold water circulates, which serves to keep the acid below 70° F. during the process of conversion. At the rear and top of each trough is an iron shelf or grating, upon which the partially converted cotton is squeezed, and above this is an iron rod to which a hook in the end of the lever press is attached during the process of squeezing. Only four of the troughs are used for dipping the cotton in, the first being used as a reservoir for acid for immediate consumption. The troughs are placed side by side under a wooden hood, and a flue in the rear of this hood leads the acid fumes evolved into a vacuum chamber at the rear which connects with the suction pipe of the ventilating fan that ejects the fumes through a flue in the roof the factory.

**Acids.** The acids employed in the manufacture are purchased according to the following specifications:

The mixed acid to consist of one part, by weight, of nitric acid to three parts, by weight, of sulphuric acid. The nitric acid must have a real specific gravity of 1.5, at a temperature of 15° C., and be free from chlorine and its compounds. The color must not be darker than straw. The acid must not contain sulphuric acid in

sufficient quantities to perceptibly raise the specific gravity. The sulphuric acid must have a real specific gravity of not less than 1.845, and be clear and colorless. The acids are delivered in wrought iron cylindrical drums 3 feet 3 inches long, 28 inches in diameter, and 1 inch thick, and each holding about 1,200 pounds of mixed acids. With the present knowledge of mixed acids there is no certain method of inspection except by the Chemist from the Station making an examination of the separate acids at the acid works before the acids are mixed, and then supervising the mixing. By thoroughly studying the question means will undoubtedly be discovered for determining whether or not the mixed acids conform to the specifications, but this has not yet been accomplished. A preliminary investigation has, however, shown that the specific gravity of the mixed acids is not the mean specific gravity of the components, and that a contraction in volume has taken place. The examination is complicated by the fact that the acid as received contains a white, finely divided solid in suspension which does not settle completely until standing for two weeks or more. To remove it by filtration is in the nature of things a difficult operation. This suspended solid appears to be a basic sulphate of iron resulting from the slight action of the acids on the metal of the drums. Notwithstanding this action these drums offer the cheapest, safest and altogether the most practical means of transporting the acids. Before their use the separate acids were transported to the Station in glass or acid-proof stoneware carboys and mixed when desired for use. While this method gave a better check on the quality of acid delivered, the serious fires and accidents which resulted from breakage during transportation led to its abandonment. The acid from the drums is pumped into large acid-proof stoneware reservoirs in the dipping room, and from there it is led by a conductor into the dipping troughs.

**Dipping the Cotton.** The cotton is weighed out in one pound lots. Each lot is then divided into three nearly equal parts which are successively and rapidly worked into the acids in the dipping trough by means of the steel fork, the separate portions being

well stirred about in the acid to prevent any local rise in temperature. When the whole is immersed a 10-minute sand glass is turned and the "dipper" passes on the next trough where this operation is repeated. By the time he has filled the fourth trough with its charge the sand has run its course above the first trough, so this charge is withdrawn from the acid, placed upon the grating and squeezed by the lever press as completely as possible and then placed in the digestion pot.

**The Lever Press** is an iron bar about 5 feet long having a hook at one end. A plate is attached to the bar by a pivot about 8 inches from the hook. To use the press the hook is attached to the rod above the dipping trough, the plate is placed on the cotton and pressure is applied to the longer end of the lever.

**Digestion Pot.** This is an ordinary two-gallon crock made of coarse stoneware, glazed inside and out, and provided with a cover. It is of the first importance that the pot should be sound and the glaze intact so that no leaking can take place, for if moisture should reach the charge in the crock the latter would be "fired." Immediately before use the pots are wiped out with a little acid so as to remove any moisture which may have accumulated or condensed on their walls. This process is technically known as "drying-out." The mass of partially converted cotton saturated with acid weighs, as placed in the pot, from 10 to 12 pounds. When it is put in the pot it is squeezed down compactly by means of a hand press, and the pot is then covered and placed in water in the cooling trough where it remains over night. A gang of two men can thus treat 100 pounds of cotton in a working day of 8 hours.

**Cooling Troughs.** These are made of wood 2 inches thick, are rectangular in shape, are lined with lead and provided with a water tap at one end and an overflow pipe at the other. The latter pipe is just high enough and of such size as to prevent the water in the trough from rising above the level of the acid and gun-cotton in the pots. The troughs are 1 foot 5 inches wide, 8½ inches deep, and 24 feet 6 inches long. Each one will hold 20 pots. Six are used and one is reserved for emergencies. Cold

water is kept circulating through these troughs in summer, but in winter they are simply filled with water. From the cooling troughs the gun-cotton passes to the

**Acid Wringer.** This is a centrifugal wringer made of mild steel and provided with a cover to prevent the acid or acid fumes from escaping. The wringer is 20 inches in diameter and 9 inches deep, has a  $\frac{1}{8}$ -inch mesh and makes 1,400 revolutions per minute. It is provided with a flue leading to a ventilating fan by which the fumes are driven into the outer atmosphere, while a pipe from the bottom leads the extracted acid in a receiver in the factory cellar. Before using for the day this wringer is "dried out" by pouring in a pitcher-full of acid and rotating the basket. Two pots full of gun-cotton are wrung at one operation, and this occupies from three to four minutes. The operation should be conducted with caution, and extreme care should be taken that no moisture or oil reaches the mass. As the digestion pots have been immersed in water in the cooling troughs, it is necessary to let them drain and to dry their outer surface before taking them to the acid wringer. Several explosions or "firings," which have taken place in wringers, have been traced to drops of oil from the machinery, or of perspiration from the faces of the workmen, which have fallen on the gun-cotton. The wrung gun-cotton is taken from the wringer by hand, the hands being covered with rubber gloves, and it then passes to the

**Immersion Tub.** This is a wooden tub of 800 gallons capacity provided with a perforated false bottom, and having a  $3\frac{1}{2}$ -inch inlet and a  $3\frac{1}{2}$ -inch outflow pipe. At one end is a wooden drum 2 feet in diameter provided with feathers, and placed so as to be nearly one-half immersed in the water of the tub when the tub is filled. This cylinder rotates horizontally about its axis and serves as a beater to carry the gun-cotton under the water. Above the tub and at one side of the beater is placed a wooden box or hopper, lined with lead, which is provided with a door in the side through which the gun-cotton is introduced into the hopper, and a slot in the bottom by which the gun-cotton is fed to the tub. The object of the immersion process is to wash out the greater portion of acid from the gun-cotton. As stated above, a small

quantity of water is likely to cause firing, hence to effect this washing successfully, it is necessary to use very small portions of gun-cotton at a time, to use very large quantities of water so as to drown the gun-cotton and to perform the operation so quickly that the acid is removed from the gun-cotton and distributed through the great body of water before any local heating can take place. This is effected as follows: The tub being filled with water, the water flowing at full speed, and the beater being in rotation, two crocks of wrung gun-cotton are placed in the hopper. Then the workman inserts his hand protected by a rubber glove and little by little pushes the gun-cotton through the slot, and this operation is repeated until fifty crocks are fed into the tub. When well washed the gun-cotton is placed in a wooden rack to drain. Owing to the scarcity of fresh water at the Torpedo Station salt water is used in the immersion tub, so the gun-cotton from the tub is wrung out in a centrifugal wringer, and washed with fresh water until the salty taste has disappeared. Two crocks full are wrung at a time, and three washings are generally sufficient. No matter how much the gun-cotton is washed in cold water it still retains acids or easily decomposed material which can only be removed by boiling, hence from the immersion tub the gun-cotton passes to the

**Second or Gun-cotton Boiling Tub.** This consists of a wooden tub of 300 gallons capacity, which is provided with a perforated false bottom and heated by a steam coil. The inlet pipe and coil are cut off from the interior of the tub so that the metal cannot come in contact with the gun-cotton. Here fifty pots of gun-cotton are boiled for eight hours in fresh water to which 10 pounds of carbonate of soda have been added, then drained over night, washed with fresh water in a centrifugal wringer, returned to the boiling tub, boiled with fresh water for eight hours, again drained over night and again washed with fresh water in the centrifugal. The gun-cotton next passes to the

**Pulper.** This machine is the ordinary "beater," "rag engine," or "Hollander," used in paper mills, and consists of a wooden tub 12 feet long, 5 feet wide, and 2 feet deep, with curved ends. The tub is partially divided along its longer axis by a wooden partition (of the same height as the walls of the tub) into two

parts—the “working side,” in which the gun-cotton is shredded between the knife edges on the revolving cylinder and those on the “craw,” and the “running side,” into which the shredded material is thrown by the revolving cylinder. The revolving cylinder is of wood, is 28 inches in diameter, 28 inches long, carries forty crucible steel knives and rotates two hundred times a minute. Under the cylinder is a massive oak block, called the “craw,” the concave surface of which equals one-fourth the circumference of the cylinder. The side of the block leading to the curved face is gently inclined, while on the side beyond the curved face it is sharply inclined. In the center of the craw below the revolving cylinder is fitted a box of steel knives, and the cylinder is so adjusted by set screws attached to the socket in which its shaft revolves that its knives just clear the bundle of knives in the craw. The cylinder is enclosed in a wooden cover, extending nearly the length of the partition, to prevent loss of the material by centrifugal action. From 300 to 350 pounds of gun-cotton are slowly fed into the pulper, and water is added until, when the cylinder is revolving, the mass just reaches the top of the tub to the right of the cylinder. During the feeding the gun-cotton is held in a wall-pocket made of thin boards and canvas, which is placed at the left-hand end of the pulper. When the cylinder is set in revolution the gun-cotton is drawn between the knives and shredded and the paste forced over the craw, where, as it flows sluggishly, it is heaped higher than at the other end of the tub, but it generally flows to the other end, is drawn again between the knives, and so it continues until the whole of the gun-cotton is cut to the fineness of corn meal. When the pulper is in good working order this operation takes two days for a charge of the size stated above. The mass is then run off into the

**Poacher.** This is a wooden tub similar in form to the pulper, but the cylinder is armed with wooden feathers instead of knives, and it serves simply to keep the gun-cotton in suspension in the water and to keep the whole mass in rotation about the tub. The poacher has a capacity of about 900 gallons. When the pulp has reached the poacher, the gun-cotton is allowed to settle, and the water is drained off by means of a telescopic overflow pipe in one end of the poacher. The tub is filled with fresh water, the

cylinder set in revolution and the circulation kept up for one hour, when the settling and draining is repeated, and these operations are continued for two days, making about six washings and settlings, when a sample is drawn and tested. If the sample fails to pass the test the washing in the poacher is continued until the gun-cotton will pass. When thoroughly washed the gun-cotton is again drained, three pounds of precipitated chalk, three pounds of caustic soda, three hundred gallons of lime water, and sufficient water to make the whole up to about 800 gallons, are added to it, and the whole is sucked up by means of a vacuum pump into the

**Stuff Chest.** This is a cylindrical iron vessel of about of 850 gallons capacity fitted with a man-hole at the top which is closed by an air-tight cover, and provided at the bottom with an inlet pipe through which the pulp enters, and an outlet pipe through which the pulp is delivered. Through the center of the tank is a vertical shaft, which is provided with four feathers, and which is geared to a horizontal shaft above it. The object of this stirrer is to keep the gun-cotton and other solids uniformly suspended in the liquid so that the same proportions of each, as nearly as possible, may be delivered to the molding press. The stirrer is run for about twenty minutes before the molding begins, and is kept in operation until the molding ceases. The stuff chest rests upon stringers at the top of the factory so that its contents may gravitate to the press. The pulp first goes, however, to the

**Wagon,** which is a cylindrical copper vessel of about 25 gallons capacity suspended by rollers upon a railway so that the top of the vessel just clears the outlet pipe of the stuff chest, while the bottom is well clear of the top of the molding press. Inside the wagon is a vertical stirrer, similar to that in the stuff chest and playing the same part, which is geared to a horizontal shaft that rotates between the rails. The pulp is delivered by an orifice in the bottom, which is closed by a valve which moves vertically and is operated by a lever and cord at the top of the wagon. A one-inch rubber tube one foot long is attached to the outlet of the wagon so as to assist in delivering the pulp at the desired point. The wagon is filled by rolling it under the stuff chest and opening the valve in the outlet pipe of the latter. The stirrer then being

in rotation the wagon is rolled along until it reaches the molding press, when the rubber tube is led successively to each compartment of the molding press, the lever is pulled and the press is loaded. One wagon load serves for about three charges for the molding press.

**Molding Press.** This is a hydraulic press made of bronze and containing four rectangular compartments 2.8 inches square with chamfered corners. The press is closed by a block which is hinged at the back and locked at the front by a lever clamp swivelled eccentrically. The pistons have a 28-inch stroke. Through the center of each piston-head is a rod  $1\frac{1}{2}$  inches in diameter, which is screwed in the base of the press and reaches quite to the top, and which is used as the core to form the detonator hole in the gun-cotton block. The top of each compartment is closed by a plate perforated with holes through which the water, which is squeezed out of the pulp, escapes and flows into the reservoir between the compartments. The finished gun-cotton block is 2.9 inches in diameter,  $3\frac{7}{8}$  inches in diagonal (the corners being chamfered) and 2 inches in height, and to produce this it is necessary that the molded block should be 2.8 inches in diameter, and  $5\frac{1}{4}$  to  $5\frac{1}{2}$  inches high, when the molding pressure is 100 pounds to the square inch. Knowing the size of the compressed block desired, it is determined, by experiment, how much of the pulp is necessary to produce it, the length of the stroke of the piston being increased or decreased to produce this result. The pistons having been set, by means of the rod in the center of the piston-heads, the pulp is run in until the compartment is filled, and this is repeated with each of the four compartments. The perforated plates are inserted, the cover closed and locked, and the pressure applied. The pressing occupies four minutes. When primers (smaller discs or blocks) are desired only one-fourth the quantity of pulp is taken, and the molded blocks have but one-fourth the height of the service blocks.

**Final Press.** This press is a Sellers' hydraulic press, made of steel, with an 18-inch ram. On the head of the ram are nine pistons which fit neatly into nine apertures in the press block above them. The press block is made of gun-bronze, and it is 15 inches wide, 22 inches long and 7 inches thick. It is supported



in place by being bolted to the vertical columns which support the head of the press. Above the press block is a traveling block which is hung by rollers on a horizontal track, so that it may be brought in contact with the top of the press block, or pushed off from it at will. Two perforated steel plates which neatly fit the aperture, one, which is  $1\frac{1}{2}$  inches thick, above, and one, which is one inch thick, below the gun-cotton block, and these diaphragms serve to distribute the pressure uniformly over the surface of the blocks, while the perforations allow the water, which is squeezed from the block, to escape. The upper plate also bears on its lower surface the marks which it is desired to impress on the block, and thus serves as a die to stamp the gun-cotton.

A very detailed account of the history of each charge is kept in the factory, and the system of marking enables those in charge to keep track of each charge until it is expended.

The press is loaded by rolling off the traveling block, lowering the pistons, dropping in the lower plates, then the molded gun-cotton blocks, then the upper plates, and, finally, rolling the traveling block back into place again. The pressure is then applied by means of a powerful hydraulic pump in a pit beside the press, the safety valve of which is set to discharge at from 1,800 to 2,000 pounds as indicated by the pressure gauge. Of course the total effect of the ram will be transmitted to the pistons and, as the area of the head of the ram is to that of the nine pistons heads as 3.4 : 1, the pressure per square inch on the gun-cotton will be 6,120 pounds when the initial pressure is 1,800, and 6,800 pounds when the initial pressure is 2,000. The pressure reaches the maximum about three minutes after the pump is set in operation, and this pressure is maintained for about one minute by the sand glass. When the ram is released the traveling block is rolled off, the pump is set at work again, and the finished blocks of gun-cotton are pushed to the surface of the press block. When priming blocks are to be pressed, four of the molded blocks are inserted in each of the compartments of the press block, and they issue firmly compacted together, but showing distinctly the marks of demarcation of each of the molded blocks, and they may be readily split apart along these lines. When the gun-cotton is taken from the final press it contains from 12 to 16 per cent. of

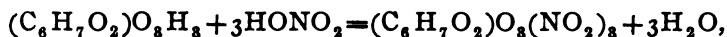
moisture. It is but natural to apprehend danger from subjecting gun-cotton, which is so nearly dry, to the high pressures which are employed, especially when we consider that small particles of the substances might get pinched between the metal parts, and that some of these might be air-dried while the press is idle. It has been reported that such explosions have occurred in this way abroad, but it has been impossible to verify these reports.

However, no such explosions have thus far occurred at the Torpedo Station, though the press block was once split open. As far as could be ascertained, this was due to the workman's having inadvertently inserted three of the perforated plates into one compartment and only one into another, thus causing the whole force of the ram to be exerted on one piston, which bent and jammed and finally split the block. The gun-cotton from this pressing was recovered intact from the press block. To guard against serious results following an explosion at the Station, the press is surrounded by a rope mantlet (such as was used in monitor turrets during the war of the Rebellion), which is braided from Manilla rope  $1\frac{1}{2}$  inches in diameter. There are four thicknesses to the mantlet, and this can be relied upon to arrest pieces of the metal if projected with not too great velocity. When the gun-cotton blocks are taken from the press they are two inches in height, but after standing awhile they swell a little. Though, when taken out, they contain but from 12 to 16 per cent. of water, as sent into the service they contain about 35 per cent. This is added by allowing the blocks to soak in a trough of fresh water until they cease to absorb water.

**Storage of Gun-cotton.** The blocks are packed in the torpedo cases at the gun-cotton factory as fast as they are made, the primer cases being filled with wet primers. A sufficient proportion of dry primers are sent with each outfit, and when the torpedoes are desired for use the wet priming blocks are withdrawn from the primer can and dry ones substituted. These wet ones are then dried by splitting the blocks apart into  $\frac{1}{2}$ -inch portions, weighing each one, stringing them on a perfectly clean brass or copper rod or tube, separating the blocks one from another, and

suspending the rod in a suitable dry place (away from any direct source of heat) where they will be freely exposed to air and yet be under cover. The blocks are to be weighed separately from time to time, the weights being marked on each with a soft lead pencil, and they are to be dried until they cease to lose weight.

**Yield of Gun-cotton.** According to the equation



we should obtain 183.3 pounds of gun-cotton from 100 pounds of cotton. If, however, we follow Vieille and consider gun-cotton as cellulose endeca-nitrate, we should obtain, theoretically, 176 pounds of gun-cotton. At the Torpedo Station, notwithstanding the loss incident to the many manipulations, about 150 pounds of gun-cotton are obtained from 100 pounds of cotton taken from the final drier. This makes about 230 full-sized blocks.

## LECTURE XIV.

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### SERVICE TESTS FOR GUN-COTTON.

There are several standard tests which, applied to gun-cotton, either during the process of manufacture, or at any subsequent time to the finished product, determine its chemical character. They are as follows:

1. Determination of moisture in gun-cotton.
2. Determination of ash of gun-cotton.
3. Test for the presence of free acid.
4. Heat, or Stability test.
5. Solubility test.
6. Test for unconverted cotton.
7. Test for nitrogen in gun-cotton.
8. Determination of alkaline substances in gun-cotton.

Of these tests, but two—the stability and solubility—are applied during the process of manufacture.

**Preparation of Unfinished Gun-cotton for Testing.** Before applying the tests, the gun-cotton must be carefully prepared beforehand. In case of the unfinished gun-cotton, about one quart of the pulp is taken from the poacher after having been subjected to about six washings. As it is of the greatest importance that the sample tested should represent the average composition of the charge in the poacher, it is drawn in very small quantities at the time, while the revolving cylinder is in operation, and the pulp is circulating actively, portions being taken from both top and bottom.

The sample is allowed to stand until the gun-cotton has settled, when the water is poured off, and then one-half of the gun-cotton is wrapped in a thoroughly clean linen cloth and placed under a hand press, where it is subjected to a tolerably severe pressure for about three minutes, or until water ceases to flow from it.

The mass is then taken out in the form of a cake, which is broken up into fine particles and rubbed between the hands. About 13 grammes (or 200 grains) of this gun-cotton are then placed in a paper tray which is placed upon the top of an oven heated to 120° F., care being taken that the tray does not come into contact with the walls of the oven. The mass is thus heated with constant stirring for fifteen minutes. When perfectly dry, the sample is transferred to a covered glass funnel with roughened sides, the neck of which is connected with a bellows through an ordinary aspirator bottle. The mouth of the funnel is covered with a piece of clean muslin, and by means of the bellows the finest particles of the gun-cotton are blown on the sides of the funnel, from which they are carefully removed. After these particles have been exposed to the atmosphere of a normally dry and warm room for about two hours, the sample is ready for testing.

**Preparation of Finished Gun-cotton for Testing.** For these same tests—stability and solubility—the finished gun-cotton must be prepared in a manner similar to that just described for the pulp. A disc or block of gun-cotton is split and then, by gentle scraping or rasping, about 40 grammes (or 600 grains) are removed from the centre of the mass. This is placed in a litre flask, and a half litre of distilled water at a temperature of 39° C. poured upon it, when the flask is corked and shaken vigorously two or three minutes. The contents of the flask are then filtered through muslin, and then, wrapped in the filter, are subjected to a moderate pressure in a hand-press. This operation is repeated three times, when the sample is dried, and the rest of the preparation is in all respects precisely the same as that described for the pulp.

**Determination of Moisture in Gun-cotton.** The amount of moisture in gun-cotton is readily determined by weighing carefully two grammes of the cotton as it is scraped from the disc or block in a watch crystal, and placing it in an oven at 40° C. for twelve hours, at the end of which time it is placed in a dessicator over sulphuric acid and dried to constant weight. The loss of weight gives the moisture, whence the percentage of moisture is calculated.

**Determination of Ash of Gun-cotton.** This may be done as follows: Melt a little pure paraffin in a weighed crucible (porcelain or platinum) by gentle heat, and add a known weight (2 grammes) of the sample. Ignite the mixture from above, and when all is consumed ignite the crucible over a lamp, and then allow it to cool, and re-weigh. The increase in weight gives the ash.

**Test for the Presence of Free Acid.** Put about one gramme of the cotton scraped from the disc in a test-tube (25 c. c.), half fill the tube with distilled water, cork the tube or close it with the thumb and shake vigorously for a few minutes. Allow the cotton to settle, and test the supernatant water with litmus paper. Should free acid in considerable quantity be found, the subsequent tests are unnecessary, except as additional proofs of the unsafe condition of the gun-cotton.

**Heat or Stability Test.** The causes of the decomposition of gun-cotton have already been alluded to, as well as the unstable and dangerous condition of the explosive during the decomposing stage. The object of the heat test is to determine the exact character of the gun-cotton at any time as regards its stability. The test itself depends upon the principle that *when potassium iodide is decomposed in the presence of starch, the iodine is liberated and reacts with the starch to form a colored body.* This decomposition of potassium iodide is effected by the oxides of nitrogen and nitrogen acids, and in this test the heat of the bath drives off any free acids present in the gun-cotton, or decomposes any unstable bodies, and liberates the nitrogen oxides or acids which react on the test paper, producing the color referred to. As this test is applicable to all explosives containing the nitrogen oxides or acids, it will be described at length.

**Apparatus and Materials Required for the Heat Test.**

1. *Water Bath.* This consists of a glass globe, about eight inches in diameter, which is filled with water to within a quarter inch of the top when the water is heated. The globe is open at the top, and the mouth is closed by a copper plate, which is perforated with a small hole in the center to receive the thermometer, and with several holes about the central one of slightly larger diameter than that of the test tubes. Around each of these holes and attached to the under face of the cover are four spring clips inclined

toward each other, so that when the test tubes are inserted in the holes, the clips close firmly about them and hold them in any desired position. The globe is placed on strips of wood in a metallic vessel, about ten inches in diameter, and both globe and bowl are then filled with water. This outside bowl enables us to readily heat the apparatus without the danger of breaking the glass globe, while the large quantity of water is of material assistance in keeping the temperature constant for a considerable period of time.

2. *Temperature Regulator and Thermometer.* In making the test it is of the greatest importance that, during the entire time that the test tubes containing the sample are immersed, the temperature should remain perfectly constant. Wherever gas is available for heating purposes in the laboratory, this is easily managed by means of a thermostat. When gas is not at hand, by careful attention to the flame of either an oil stove or spirit lamp, the temperature can be regulated during the test. The temperature is noted by means of an accurate thermometer introduced into the bath through the central hole in the cover of the globe.

3. *Test Tubes.* The test tubes should be from 12 to 14 cm. long, and of such diameter that each will hold from 20 to 22 c. c. of water when filled to the height of 5 inches. They should be marked with a ring, drawn around them with a diamond,  $2\frac{1}{2}$  inches from the bottom, and the explosive should be compressed to this mark. Clean glass rods are used for pressing the gun-cotton in the tubes. They should be provided with flat heads and be long enough to easily reach to the bottom of the tubes.

4. *Test Paper Holders.* These consist of small glass rods about 20 cm. long having a piece of platinum wire about one centimetre long fused into one end, and bent into a hook. These rods pass loosely through holes in taper corks which fit neatly in the mouths of the test tubes.

5. *Test Papers.* The test paper used is known as *starch and potassium iodide* paper, and is made as follows: Forty-five grains of white starch, which has been well washed in cold distilled water and thoroughly dried, are added to  $8\frac{1}{2}$  ounces of distilled water, and the whole is heated to boiling, with constant stirring, and is kept gently boiling for ten minutes. Fifteen grain of pure potassium iodide (i. e., KI which has been recrystallized from alcohol)

is now dissolved in  $8\frac{1}{2}$  ounces of distilled water, and the two solutions are mixed and allowed to cool. Strips or sheets of fine white filter paper, which have been previously washed in distilled water and redried, are dipped in the above solution and allowed to remain in it for not less than ten seconds, when they are removed and hung up to dry in a warm, dark room which is free from laboratory dust and fumes. When dry, the upper and lower margins of the strips or sheets are cut off and the paper is preserved in well stoppered, dark colored bottles, or in ordinary bottles which are kept out of contact with the direct rays of light. For use in making the test, the paper is cut into small rectangular pieces, 10 mm. by 20 mm. (about  $\frac{4}{10}$  by  $\frac{8}{10}$  of an inch). They are attached to the test paper holders by piercing them near the top with the point of a knife, two incisions being made at right angles to each other forming a cross. The point of the platinum wire is inserted through the center of the cross, and the hook is bent firmly together so as to hold the papers rigidly in line with the rod of the holder.

6. *Glycerine Solution.* This is made by dissolving ten per cent of pure glycerine in distilled water. It is kept in a small flask, the mouth of which is closed by a cork, and the latter is perforated to receive a small glass rod which is long enough to reach the bottom of the flask, and drawn to a point at its lower end. The glycerine solution is used to moisten the test paper, and is applied by holding the test paper holder vertically with the paper uppermost, and then touching the paper at the edge where it is fastened to the platinum hook, with the rod just as it is drawn from the solution. Enough solution is applied to thoroughly moisten the paper across its entire width and for one-half its length. The holder is held with the paper upward until the solution has been drawn by capillarity up to the middle of the paper, and is found to go no further.

7. *Standard Tint Paper.* As in all tests depending upon a comparison or determination of color, considerable difficulty is encountered practically in conducting the heat test, especially by inexperienced operators. And since it is of the greatest importance that the exact moment at which the coloration upon the



test paper reaches the proper depth or shade should be noted, a standard tint paper has been devised to aid observers in this determination.

It is prepared by making a caramel solution in distilled water of such concentration, that when diluted one hundred times (10 c. c. made up to a litre) the tint of the solution equals that produced by the Nessler test (2 c. c.) in 100 c. c. of water containing 0.000075 grammes of ammonia, or 0.00023505 grammes of ammonium chloride. With this solution lines are drawn on slips of white filter paper by means of a clean quill pen. When the slips are dry they are cut into pieces of the same size as the test papers, and in such a way that each piece has a brown line across it near the middle of its length, and only those strips are preserved in which the brown line has a breadth varying from  $\frac{1}{2}$  to 1 mm. ( $\frac{1}{25}$  to  $\frac{1}{50}$  of an inch). This may be used by hanging a strip in a test tube beside the tube in which the test is being made, and noting each until a brown (or yellow) line appears on the test paper, similar in depth or shade to that in the standard tint paper.

**How to Make the Heat Test.** Insert the thermometer in the bath to a depth of about three inches, and apply the heat until the temperature is constant at  $65^{\circ}.5$  C. ( $150^{\circ}$  F.) The weighed sample of gun-cotton (20 grains) is introduced into the tube and pressed down by means of the glass rod to the mark, and the tube is closed with a loosely-fitting cork. The tube is then inserted in the bath until the upper surface of the sample coincides with the level of the water, *and the exact time of insertion is noted.* The test paper is *now* moistened with the glycerine solution, the paper being drawn up close to the bottom of the cork. The holder with the test paper attached is substituted for the cork in the test tube. Shortly after the test tube has been introduced into the bath, a ring of moisture will begin to form in the upper part of the tube. As soon as this is observed, the test paper is lowered by pushing the rod through the cork until the *line of demarcation between the wet and dry portions of the paper is coincident with the lower edge of the ring of moisture.* The test paper is now closely watched, and *as soon as the faintest sign of discoloration appears on the test paper* (and it

appears at the line of demarcation between the wet and dry portions), *the time is again noted*. When the standard tint paper is used; the second time is taken when the two colors (that on the test paper and that on the standard tint paper) are of precisely the same depth or shade.

The time elapsed for stable gun-cotton must not be less than *fifteen (15) minutes*. In the U. S. Artillery School Laboratory, it is customary to make three tests of each sample at the same time, using as many tubes, and introducing them in rapid succession, so that the conditions may be practically the same, and the mean of the three tests is taken. The record is kept as follows:

U. S. ARTILLERY SCHOOL,  
DEPARTMENT OF CHEMISTRY AND EXPLOSIVES,  
*January 23, 1890.*

HEAT TEST OF GUN-COTTON.

Sample: Torpedo Station, Charge 100, 1889.

	1	2	3	
Time of stopping,	10.51	10.53	10.55	
Time of starting,	10.30	10.33	10.38	
Time elapsed,	21	20	17	
Mean	.	.	.	19 m. 20 s.

Condition of sample: *Stable*.

-----  
.... *Lieutenant, .... U. S. Artillery,*  
*Operator.*

**Solubility Test.** This test depends upon the principle that *the lower cellulose nitrates are soluble in a mixture of ether and alcohol, while the tri-nitro-cellulose is insoluble in such a mixture*. This test logically follows that just described exactly as the heat test follows that for the presence of free acid. By this test we determine the presence or absence of the lower or unstable nitro-compounds, and taken in connection with the nitrogen test which will be described later, we are able to determine very closely which particular compound is the cause of trouble, and therefore the exact character of the explosive.

About 20 grammes of the pulp from the poacher, or 10 grammes of the finished product, are treated in the hand-press as described for the heat test, and the cake is then broken up and placed in an air bath where it is dried at a temperature of 40° C. for about two hours, being rubbed between the hands occasionally to break up the lumps. When well dried it is removed from the bath and exposed to the air for an hour. Two grammes of the sample thus prepared are weighed out in a watch crystal and carefully introduced into a flask, and covered with four fluid ounces of a mixture of *one volume of absolute alcohol* and *two volumes of Squibbs' strongest ether*. The flask is then corked and shaken at intervals for two hours. At the end of that time the contents of the flask are decanted upon a weighed linen or muslin filter (which has been previously washed in some of the ether-alcohol mixture) and washed on the filter with four ounces more of the mixture; the filter and contents are then squeezed thoroughly to remove any of the solution present. (The funnel in which the filter is placed is introduced into a perfectly clean bottle, so that the mixture may be saved for distillation and future use.) The residue in the filter is carefully removed by means of a glass spatula and is replaced in the flask and covered with four ounces of fresh ether-alcohol. The flask is again corked and shaken at intervals for one-half hour, and the contents are then decanted upon the same filter as before and washed with four ounces more of the ether-alcohol mixture. The filter is again squeezed, and then, with its contents, is spread upon a perfectly clean glass plate, and placed in a drying oven and heated until all odor of the alcohol has disappeared. It is then exposed to the air for two hours and weighed. The drying and exposure to the air are repeated until the weight is constant. The difference between the weight of the gun-cotton taken and that of the residue found gives the weight of the substance dissolved, whence the percentage is readily calculated. The soluble matter in gun-cotton should not exceed 10 per cent. The gun-cotton made at the U. S. Naval Torpedo Station contains usually less than 6 per cent.

On account of the expense, it is usual to take the mean of two tests at the U. S. Artillery School Laboratory as sufficient to es

tablish the percentage of soluble matter. The record is kept as follows:

U. S. ARTILLERY SCHOOL,  
DEPARTMENT OF CHEMISTRY AND EXPLOSIVES,  
*January 27, 1890.*

SOLUBILITY TEST OF GUN-COTTON.

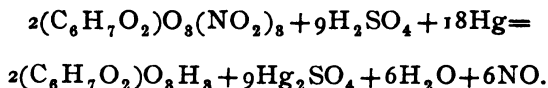
Sample: Torpedo Station, Charge 100, 1889.

	1	2
Weight of sample (in milligrammes)	2,000	2,000
Weight of filter, . . . . .	2,955	3,008
Weight of sample and filter, . . . . .	4,955	5,008
Weight of insoluble gun-cotton and filter, . . . . .	4,821	4,891
Weight of soluble gun-cotton, . . . . .	134	117
Mean, . . . . .		125.5
Percentage of soluble gun-cotton, . . . . .		6.275

-----  
.... *Lieutenant* .... U. S. Artillery,  
*Operator.*

**Test for Unconverted Cotton.** Besides the determination of the soluble gun-cotton, it is sometimes necessary to determine the amount of unconverted cellulose present. This may be done by treating the residue from the ether-alcohol washing with ethyl acetate (acetic ether). By digestion with this solvent, the cellulose nitrates are dissolved, and the unconverted cellulose is left behind and may be collected on a weighed filter. Or, it may be treated, by boiling, with a solution of sodium stannite made by adding caustic soda to a solution of stannous chloride until the precipitate at first formed is just redissolved. This solution dissolves the cellulose nitrates, but does not affect cellulose.

**Test for Nitrogen in Gun-cotton.** This test depends upon the principle that *when cellulose nitrates are treated with pure concentrated sulphuric acid in the presence of mercury, they are decomposed, all of the nitrogen being evolved in the form of nitrogen oxides*, which may be collected and measured, whence the percentage of nitrogen may be easily calculated. Should the nitrate under examination be the tri-nitro-cellulose, the reaction would be represented as follows:



Similar equations may be written to represent the reactions which occur in the cases of the other nitrates, and from the percentage of nitrogen found, we are able to decide very approximately the particular nitrate, the presence of which is the cause of trouble.

The test is easily made by means of a nitrometer, the form used in the Artillery School Laboratory being that devised by Bunté for gas analysis. This apparatus consists of two glass tubes of about 150 c. c. capacity connected at their lower ends by means of a rubber tube. The upper end of one of the tubes is fitted with a thistle bulb funnel, between which and the tube proper is a three-way stop-cock; there is also an ordinary stop-cock fitted at the lower end of this tube. This tube, which is called the burette, is graduated into tenths of cubic centimetres, while the other tube, called the filling tube, is ungraduated. Both tubes are mounted in a burette-holder so as to be vertical and side by side, but either may be raised or lowered at will. To conduct the test, the nitrometer is first filled as follows: The rubber tube having been securely attached, the graduated tube is firmly clamped in the burette-holder and both stop-cocks opened; then, holding the plain tube in the left hand so that it is raised about two-thirds of its length above the graduated one, pour into the nitrometer through a funnel fitted in the plain tube enough mercury to completely fill the graduated tube and partially fill the plain one. Then close the upper stop-cock of the graduated tube and secure the plain tube in the burette-holder along side of the former and on a level with it. Next introduce into the funnel at the top of the burette 300 milligrammes of thoroughly dried, finely divided gun-cotton and cover it with 5 c. c. of pure concentrated sulphuric acid. The upper stop-cock is then *very carefully* opened, and the mixture is swept into the tube, additional acid being added to wash every particle of the gun-cotton into the tube. *It requires the most careful manipulation at this point in order that the flow of acid may be constant and that no air gets into or gases escape from the tube, in either of which events the results are vitiated.*

It is well to have an excess of acid so that the stop-cock may be closed before the last traces of the acid run into tube. The reaction begins as soon as the mixture reaches the mercury, and is assisted from time to time by closing the lower stop-cock of the burette, removing it from its clamp and shaking it carefully. After the reaction has entirely ceased (usually at the end of one-half hour), the tubes are adjusted so that the mercury in each is at the same height, and the exact amount of acid in the burette noted. The filling tube is then raised so that the level of the mercury in it is higher than that in the burette by one-seventh of the number of divisions in the burette occupied by the sulphuric acid and *the volume of the gas is read off*. The tubes are again placed side by side, and allowed to stand for fifteen minutes when the volume of gas is verified by adjusting the tubes as before. When the readings become constant, the thermometer and barometer are noted and the volume of the gas is reduced to  $0^{\circ}$  C. and 76 cm. by Charles' and Mariotte's laws, which may be conveniently written as follows:

$$V_t = V_0 \frac{P}{P_t} \left(1 + \frac{t}{273}\right),$$

In which

$V_t$  represents the volume of the gas at the observed temperature.

$V_0$  represents the volume of the gas at  $0^{\circ}$  C.

$P_t$  represents the observed pressure of the atmosphere at the time of the experiment.

$P_0$  represents the pressure of the atmosphere at 76 cm.

$t$  represents the observed temperature at the time of the experiment.

The weight of the sample being known, from the data obtained from the methods given above, the weight of nitrogen present and the per cent. in the gun-cotton are readily calculated. If we assume the formula for military gun-cotton to be  $(C_6H_7O_2)_3(NO_2)_3$ , it should contain 14.14 per cent. of nitrogen; but if the formula be  $C_{24}H_{29}O_{20}(NO_2)_{11}$ , it should contain 13.47 per cent.

**Determination of Alkaline Substances in Gun-cotton.** For certain purposes, it is sometimes desirable to know the amount of calcium and sodium compounds present in the finished gun-cotton.

For this test five (5) grammes of air-dried gun-cotton are taken from the centre of a disc or block, rubbed up finely, and extracted by means of 100 c. c. of standard hydrochloric acid diluted with about twice its volume of water. The gun-cotton and acid are allowed to digest together for a short time, the liquid is decanted, and the gun-cotton washed either by decantation or upon a filter, until the washings exhibit no acid reaction. The washings are added to the decanted liquid, and 100 c. c. of standard sodium carbonate solution (30 grammes of  $\text{Na}_2\text{CO}_3$ , dry and fused, to one litre of water) is poured in. The amount of sodium carbonate neutralized is determined by titrating with the standard acid solution and an indicator. The unneutralized sodium carbonate is the measure of the alkalies in the gun-cotton.

In preparing the standard solutions for this test, they should be so constructed that equal volumes neutralize each other.

## LECTURE XV.

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### NITROGLYCERINE.

**Discovery and Early History.** The discovery of the fact that cotton when immersed in nitric, or in a mixture of nitric and sulphuric acids, was converted into a highly explosive substance gave rise to a warm controversy among the chemists of the day as to the nature of the change which had taken place, one party holding that the change was a true chemical one and was due to the substitution of certain of the components of the nitric acid for certain components of the cotton resulting in the formation of a new compound substance, while the other party held that it was physically impossible that so delicate a material as cotton fibre could change its elements without a more obvious change of structure, and that the change was simply a physical one due to the absorption of the nitric acid in the pores of the cotton, just as nitre is absorbed by paper in the manufacture of touch paper, and that thus the inflammability of the substance was increased.

It is obvious that with such a difference of views prevailing the true one could only be established by experimental evidence, and hence the promulgation of these views led to many experiments being made upon a large number of substances which were analogous in their chemical characters to cotton. Pelouze, the French chemist, was one of the more active advocates of the theory of exchange, and, among other experiments, he suggested to his pupil, Sobrero, that he should study the effects of nitric acid on glycerine, because, as the latter was chemically analogous to cotton, it was probable that, if the change was a chemical one, an explosive body would be formed, and it was obvious that, if an explosive body was formed, it must be due to replacement, for it was exceedingly unlikely that a liquid like glycerine could absorb and retain in its pores, by mere physical force, a liquid like nitric acid.



Sobrero made the experiment and discovered nitroglycerine, which announced its birth by a violent explosion which shattered the windows of the laboratory and wrecked the apparatus.

The great power which this explosive exhibited, and the apparent readiness with which it exploded, conspired to make chemists somewhat reluctant to pursue the investigation of the character and properties of this substance, and so, although Sobrero made his discovery in 1846, little was done with it until the Crimean War, when it was asserted that Professor Jacobi had manufactured the explosive in quantities for the Russian government, and that its reputed presence deterred the English from entering the harbor of Cronstadt, though, during this time, it was employed in very small quantities as a medicinal agent under the name of *glonoine*,

The practical use of the substance as an explosive agent is due to Alfred Nobel, a Swedish engineer, whose name is indissolubly connected with and pre-eminent in the history of nitroglycerine explosives, and who, about 1860, invented a process for its rapid manufacture which he patented under the name of *detonating oil*, or *Nobel's Sprengöl*, and between this and 1863 established factories on the continent of Europe for its manufacture on a commercial scale.

At this time Nobel used the same means for exploding the substance as were employed for firing gunpowder, with the addition, sometimes, of a priming charge of gunpowder, but it was found that, even when confined, the nitroglycerine was but partially exploded. In 1863, however, he discovered that it could not only be exploded with certainty by means of a cap containing mercury fulminate, but that the power developed when thus exploded was enormously greater than could be obtained from it by any other means. The discovery of this fact marks not only an epoch in the history of nitroglycerine but in that of all explosives, since it revealed to us the method of inducing explosion by detonation.

Great expectations were aroused by the announcement that the enormous force stored up in nitroglycerine was completely under control and could be used at will for doing useful work, and it found its way to the scene of mining operations in many parts of the world.

Scarcely a year had elapsed after Nobel had secured his patents in Norway before the substance made its appearance in this country, but the fact of its presence was announced in a very startling manner. One of the guests of the Wyoming Hotel, in New York, wishing to polish his boots drew from under the counter a small box upon which to rest his foot, the box having been used for this purpose for some time. While busy with his work he noticed a reddish vapor coming from the box and he called the clerk's attention to it. The latter took the box, carried it to the door and threw it into the street, when it instantly exploded, and so violently that the pavement was torn up, the passers-by were thrown down, and the windows in every house within 100 yards of the entrance to the hotel were shattered.

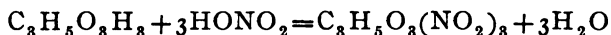
Great excitement was created by the explosion, strenuous efforts were made to learn the character of the agent which caused this disaster. On inquiry it was ascertained that some weeks previously a guest who had recently come from Germany, being pressed for means, left the box as security for his board, stating that it contained Glonoin Oil, a new material which had been used, with great success in Germany, for blasting.

Glonoin Oil was but another name for nitroglycerine.

This accident was not long after followed by one at Aspinwall, another at Wells, Fargo & Co.'s office in San Francisco, another at the factory at Stockholm, and still others which were so inexplicable and disastrous as to lead to public reprobation of this dangerous and, to most people, mysterious and diabolical compound, and many governments, among them Sweden, Belgium and England, totally prohibited its use, so that the effort to introduce it seemed destined to failure. But it was observed that these accidental explosions were exceptional, and that in repeated instances nitroglycerine had been transported long distances, both by sea and by land, and had been stored for considerable periods of time without undergoing explosion, and, as the agent was too valuable a one to be abandoned if its safety could be in any way ensured, several chemists were encouraged to further investigate its properties and to seek to discover and remove the causes which

had operated to produce these premature explosions. Notable among these investigators were the American chemists, Mowbray and Hill, and through their efforts the difficulties attending the production of a pure and stable substance have been surmounted, so that for many years past nitroglycerine has been manufactured, stored, transported and used with comparative safety and with less attendant danger than surrounds gunpowder.

**The Principle upon which Nitroglycerine is Made.** The manufacture of nitroglycerine is based upon the reaction which takes place when glycerine is brought in contact with nitric acid, and which may be represented by



in which one molecule of glycerine being acted upon by three molecules of nitric acid yields one molecule of tri-nitro-glycerine, (or better, glyceryl tri-nitrate), and three molecules of water, three atoms of hydrogen in the glycerine being replaced by the three atoms of nitryl ( $\text{NO}_2$ ) in the three molecules of nitric acid.

It is believed to be possible to produce three different nitroglycerines. By replacing one atom of hydrogen in the glycerine by one atom of nitryl the mono-nitro-glycerine is formed, having the formula  $\text{C}_3\text{H}_5\text{O}_3(\text{NO}_2)\text{H}_2$ . By replacing two of the atoms of hydrogen by two of nitryl the di-nitro-glycerine is produced, having the formula  $\text{C}_3\text{H}_5\text{O}_3(\text{NO}_2)_2\text{H}$ . By replacing the three atoms we get the tri-nitro-glycerine given in the reaction above.

It is believed also that the tri-nitro-glycerine is the only one of these compounds which is stable, and that many of the accidents which have been caused by nitroglycerine have been due to the presence of these other compounds in the tri-nitro-glycerine.

To produce pure nitroglycerine it is necessary that we should use the purest anhydrous glycerine and the purest and strongest nitric acid. The presence of any fatty impurities in the glycerine gives rise to the formation of unstable bodies which cause the decomposition and spontaneous explosion of the nitroglycerine, while the presence of iron, alumina or chlorine seriously

interferes with the separation of the nitroglycerine. It has been, difficult to obtain anhydrous glycerine and anhydrous nitric acid hence it is the custom to use the most concentrated articles to be obtained and to mix with them some substance which will absorb the water present and thus render them anhydrous. The importance of using an exsiccating substance is further shown if we refer to the reaction, by the fact that water is one of the products of the reaction, and hence, if we were to start with anhydrous glycerine and nitric acid, after a portion of the glycerine has been converted, the water formed will have so diluted the remainder that there is danger of the lower nitric esters being formed. Concentrated sulphuric acid is used as the exsiccating substance, and it is added in sufficient quantity to combine not only with the water contained in the original substances but also with all the water formed during the operation.

But in using the sulphuric acid an element of danger is introduced. The sulphuric acid removes the water by entering into chemical combination with it, a hydrate of sulphuric acid being formed, and this combination is attended with the development of heat. If the temperature is raised much above  $30^{\circ}\text{C}$ , there is danger of the nitroglycerine being exploded, or if an explosion does not result, the glycerine will be wasted by being converted into oxalic acid and other products, which may render the nitroglycerine unstable. Hence it is necessary to keep the mixture cool while the conversion is taking place, and in the process of manufacture this is effected in various ways. Such is the rationale of the manufacture of nitroglycerine very concisely stated, and upon it the various processes are based.

**Sobrero's Process.** Sobrero, the discoverer of nitroglycerine, proposed the following process for its manufacture: *One-half ounce of anhydrous glycerine* is poured with constant stirring into a mixture of *two ounces of concentrated sulphuric acid (sp. gr. 1.845)* and *one ounce of fuming nitric acid (sp. gr. 1.52)*, the temperature of the mixture being kept below  $24^{\circ}\text{C}$ . by external cooling with ice, and after the oily drops have formed on the surface, the mixture is poured with constant stirring into *fifty ounces of cold water*, The nitroglycerine will settle at the bottom of the vessel so that the super-

natant liquid may be decanted and the product purified by washing it with clear water, and drying it in small portions in a vapor bath.

**DeVrij's Process.** This process differs from that just described only in the proportions of acid used, and in the fact that the sulphuric acid is added after the mixture of the glycerine with the nitric acid has been effected.

**The Mowbray Process as Employed at the Forcite Powder Company's Works.** This process has been almost universally employed in this country, and was formerly used at the U. S. Naval Torpedo Station under the superintendence of the late Professor Hill, whence it was sometimes known as Hill's Process. Nitroglycerine is no longer manufactured at the Torpedo Station except in very small quantities for experimental purposes, therefore in order to get an idea how this important explosive is made commercially, we shall have recourse to a very brief description of the process and apparatus employed at the works of the Forcite Powder Company.

The process is that introduced into this country by Mr. Mowbray, who was the first to recognize that compressed air effected most thoroughly the mixture of acids and glycerine, and also accelerated the operation, as the compressed air in expanding absorbed heat. This method was used in Europe by Mr. Nobel who confided to the engineer Leidbeck the task of studying the details and of constructing the necessary apparatus. Leidbeck introduced the glycerine into the acid mixture in the form of a shower or spray, and effected the mixing at the same time by means of compressed air. In this way he succeeded not only in accelerating the operation, but also increased the yield of nitroglycerine. This system, completely modified by the Swedish engineer, Sundström, is at present employed by the Forcite Company. The apparatus consists of

1. An acid vat.
2. A glycerine vat.
3. A mixing apparatus.
4. An injector.
5. Three separators.
6. Three washing vessels, containing fresh water.

7. Two washing vessels, containing a solution of soda carbonate.
8. A storage tank.
9. Two discharge tanks.
10. A denitrification apparatus.

This apparatus is contained in a two-story building, the acid and glycerine vats, mixing apparatus, injector, separators and two of the fresh water washing vessels being on the upper floor, and the other parts on the lower or ground floor,

The *acid vat* is a large leaden tank in which the acids are mixed and allowed to stand and cool for twelve hours before being introduced into the mixing apparatus. For every operation six hundred (600) pounds of nitric acid and eleven hundred (1100) pounds of sulphuric acid are employed.

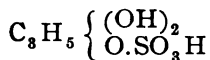
The *glycerine tank* is made of cast-iron and has a capacity of over two hundred and forty pounds of glycerine which is the amount required for a charge.

The *mixing apparatus*, also of cast-iron, is contained in a water jacket and itself contains six leaden worms through which water continually circulates during the process of conversion. The acids having been cooled as above are charged into the mixing apparatus, and the water started to circulate through the worms and jacket; the glycerine is then introduced into the same apparatus in the form of spray by means of the *injector* which works by compressed air. The reaction which results in the conversion of the glycerine into nitroglycerine begins immediately, attended with the evolution of considerable heat, hence during this period of the process the thermometer is watched constantly, and, in case the temperature should rise above 28° C. (80° F.), the flow of glycerine is at once cut off. Should the temperature still increase, and especially if the partially converted charge show signs of "firing," the faucet at the bottom of the mixing apparatus is immediately opened and the contents are discharged into the discharge tanks on the floor below. After the entire charge of glycerine has been introduced into the mixing apparatus, the water is allowed to circulate for a few minutes, and the contents

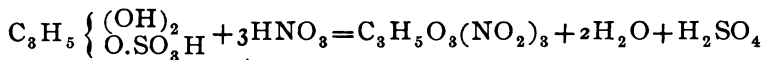
then drawn off into the *separators* (made of lead) where the nitroglycerine collects on the surface of the acid mixture. As the nitroglycerine appears, it is skimmed from the acids and poured into the *washing vessels* containing fresh water and thoroughly washed with cold water until it shows no traces of acidity. It is then drawn off into the washing vessels containing the solution of carbonate of soda and washed until it shows an alkaline reaction. Finally it passes through a cotton filter into the *storage tank* where it remains until required for use.

The *discharge tanks* have a capacity much greater than the yield of nitroglycerine during any one operation, and are kept partially filled with cold water in case of danger due to the inability of the operator to regulate the temperature during the process of conversion. After the nitroglycerine has been removed from the separators, the remaining acids are drawn off into a lead chamber or tower, called the *denitrification apparatus*, where all traces of nitro-glycerine remaining in the mixture are destroyed, and the acids saved for future use.

**Process Employed by the French Government at their Works at Vonges.** The process of Boutmy and Faucher, which is employed by the French government at their works at Vonges, differs in principle from any of those described. In this process two mixtures are first prepared, one a mixture of nitric and sulphuric acids in equal proportions, the other a mixture of one part of glycerine to 3.2 parts of sulphuric acid. These are thoroughly cooled, and then mixed together in the proportion of 5.6 parts of the nitric-sulphuric mixture to 4.2 parts of the sulphoglycerine mixture. The whole is placed in an earthen pot, surrounded only by the atmosphere, and the operation is left to take place, which it does quietly, the nitroglycerine separating as formed and rising to the surface of the liquid mass, from which it is eventually skimmed off, washed and purified. The theory of this operation is that the glycerine and sulphuric acid form the glycerol-sulphuric acid.



and that this reacts with the nitric acid as follows :



It is claimed for this process that it is simple in execution, requires but little apparatus, is safe and gives a large yield. The claim for safety is questioned on the ground that the nitroglycerine remains for a dangerously long time in contact with the acids, and the explosion at Pembry Burrows in 1883, where this process was used, is cited in support of this criticism. It may be replied that it is now the custom at the factories, where the other processes are employed, to allow the nitroglycerine and acids to remain in contact for a long time, until the nitroglycerine separates completely from the acids, so that by skimming, the acids may be recovered undiluted, and that the operation is not considered extra hazardous, while, besides, Dr. Dupré found that very impure glycerine and acid had been used at Pembry Burrows at the time of the explosion, and this was sufficient to account for its origin.

The object of separation by "skimming" is to recover the unconverted acids and thereby reduce the cost of manufacture. W. Poetsch describes the method he employs as follows: On heating the waste acids, consisting of sulphuric and nitric acids and organic nitro-compounds, at  $105^\circ$ , decomposition of the nitro-compounds ensues, oxidation to carbon dioxide take place at the expense of the nitric acid which is present. During the reaction enough heat is liberated to volatilize the remaining portion of undecomposed nitric acid and the lower oxides of nitrogen produced, pure sulphuric acid being left in the residue. Poetsch uses a closed vessel of stone or lead, having a perforated false bottom 50 cm. above the bottom. The upper space is filled with stones or broken stoneware, and heated by hot air. The waste acid is introduced in a thin stream through a funnel fitted into the cover of the vessel, and, passing over the hot stones is decomposed. The nitrogenous vapors are led through an earthenware pipe to a cooling worm, and collected in Wolff's bottles, air being introduced to oxidize the gases to nitric acid. The denitrated sulphuric acid then flows through the perforated bottom, and is run into receiving tanks.



**The Yield of Nitroglycerine from the Various Processes.**

From the equation we find that one part of glycerine should yield 2.46 parts of nitroglycerine, but this is never realized in practice. The proportion of nitroglycerine obtained is dependent almost entirely upon the acid. If the glycerine is weak the product will fall off, but the small difference in strength of glycerine ordinarily found exercises little effect. If the acids are weak, however, the product is markedly less. This does not depend to any extent upon the method or form of apparatus employed, but only upon the acid taken. Weak acids will carry smaller quantities of glycerine and give lower proportional products than strong ones; consequently statements of relative products obtained are of comparatively little value unless accompanied by a statement of the kind of acid employed and the relative amount of glycerine treated. At Vonges they obtained 1.8, while the Ardeer works get 2 parts, the loss being accounted for by the supposition that other compounds are formed which are carried away with the acids. In this country we obtain rather more than two parts. By using one part of glycerine to from 7.5 to 8 parts of mixed acids, and with care in the preparation of materials 2.2 parts can be obtained.

In all processes for making nitroglycerine the greatest care must be taken to prevent any accidental mixture of water with the charge in the converter. A very little water shows itself by the greater trouble and slowness in running and in the falling off of the product. If more water enters, the heat will be greater than can be carried away by the usual means of cooling, and the charge is "fired." Usually this means only an active decomposition accompanied by clouds of nitrous vapors.

Slight fires may be stopped by vigorous agitation, but if the firing is persistent, the contents of the tub should be run off as rapidly as possible. A constant agitation of the liquid should be kept up during drawing off to prevent separation of the nitroglycerine. When mixing the glycerine in the converter the operation is slowly performed in order to keep the temperature down, but, if the temperature is within the limit, the mixing should be performed as rapidly as possible, and the nitroglycerine removed

from the sphere of action. Rapidity of working is largely dependent upon the quality of acids used, since the heat evolved is least when the strongest acid is used. In general with highly concentrated acid, not only is the product proportionally increased, but the reaction also goes on more uniformly and is more readily controlled.

**Properties of Nitroglycerine.** At ordinary temperatures nitroglycerine is an oily liquid having a specific gravity of 1.6. Freshly made, by the Mowbray process, it is creamy-white and opaque; but becomes transparent ("clears") and colorless, or nearly so, on standing for a time, which is dependent on the temperature. When produced by "skimming" it is transparent, but it is often found in commerce to have a yellow or brownish-yellow color.

Although very slightly soluble in it, it does not mix with and is unaffected by cold water. It has a sweet pungent, aromatic taste, but is an active poison, so that mere contact with it will induce in most persons a violent sickness and an especially painful form of headache, but those constantly employed about it, as a rule, soon lose their susceptibility to its action. Strong black coffee is recommended as an antidote.

Nitroglycerine is soluble in methyl, ethyl and amyl alcohols, in benzine, in carbon disulphide, in all proportions in ether, chloroform, glacial acetic acid and phenol, and sparingly in glycerine. It is rapidly decomposed by alkaline sulphides with the separation of sulphur, and slowly decomposed by an alcoholic solution of potassium hydroxide, by ammonia, alkaline carbonates, hydrogen-sodium phosphate, hot water, ferrous chloride, hydrogen chloride and sulphuric acid (1 : 10), though, according to Hay, concentrated sulphuric acid has no action upon it. Its presence may be detected by a solution of aniline in concentrated sulphuric acid which yields a purple color with nitroglycerine, that changes to green on the addition of water.

Freshly made, opaque nitroglycerine freezes at from  $-3^{\circ}$  to  $-5^{\circ}$  F., while the transparent or "cleared" nitroglycerine at from  $39^{\circ}$  to  $40^{\circ}$  F., in both cases freezing to a white crystalline mass.

Once frozen it remains in this condition, even when exposed for some time to a temperature sensibly above its freezing point.

**To Thaw Nitroglycerine when Frozen.** When frozen it may be conveniently and safely thawed by placing the vessel containing it in another containing water not hotter than 100° F., but these precautions should be strictly observed, as most of the accidents which have occurred with nitroglycerine, and explosives of which it forms a part, have resulted from foolish and criminally careless attempts to thaw the frozen material by other means. Frozen explosives should never be put into the vessel containing the water, or brought into contact with any heated surface, except as directed above.

Pure nitroglycerine is not sensitive to friction or moderate percussion, except when pinched between metallic surfaces. If placed upon an anvil and struck with a hammer, only the particle struck, as a rule, explodes, scattering the remainder. A quantity of it has been thrown up by means of a rocket to a height of 1,000 feet, from which it fell without being exploded on impact. When, however, in a state of decomposition, it is exceedingly sensitive and explodes violently when struck, even if unconfined. It must be noted that if completely confined, the effect of a blow on pure nitroglycerine may produce explosion, since, from its liquid form, it is nearly incompressible. In the case cited above local explosion occurs only because the hammer is lifted, and the rest of the explosive is blown away, but if it was so confined that there was no escape for the effect of the explosion of the particle first struck, the whole mass would probably be fired. If nitroglycerine is freely exposed to flame it burns with a brilliant flame and without explosion. If a drop of nitroglycerine be placed on a metal plate and slowly heated up, the nitroglycerine may be completely vaporized without explosion, or if the plate be first heated to incandescence and the drop then placed upon it, the drop will assume the spheroidal condition and eventually volatilize without explosion, but if the hot plate be just below incandescence, so that the nitroglycerine can come in contact with it, the drop explodes with a violent report. The firing point of nitroglycerine is about 180° C. (356° F.), but it begins to decompose under the influence of heat at a somewhat lower temperature.

**How to Fire Nitroglycerine.** Nitroglycerine is fired by means of detonators or blasting caps containing mercury fulminate, it being more readily detonated by this means than is gun-cotton. It is essential for success that the detonator should be immersed in the liquid so as to be in direct contact with it, but when the caps are fired by means of a running fuse care should be taken that the fuse does not touch the nitroglycerine, as the latter may be set on fire before the cap explodes, and an incomplete explosion, which would produce poisonous fumes and cause a loss of energy, might then result. When fired by a gunpowder fuse only, the action is very uncertain, for sometimes the nitroglycerine is exploded and sometimes not, and even when it is exploded by this means, the force developed is much less than when it is detonated by means of a fulminate. It may be detonated, even when frozen, by means of a heavy charge of fulminate, but the action is not certain. Its insensitiveness when in the frozen condition is shown by the fact that 1,600 pounds of the liquid exploded in a magazine which contained also 600 pounds of the frozen, and that the latter was broken up and scattered in every direction without being exploded.

**Decomposition of Nitroglycerine.** Pure nitroglycerine does not spontaneously decompose at any ordinary temperature, but if it contains free acid, decomposition is apt to occur, and it is therefore very important that all acid should be removed by washing with water and alkaline solution. Quantities of nitroglycerine have been kept in the magazines at the U. S. Naval Torpedo Station for years, without special precaution having been taken to protect them, and yet they have remained entirely unaltered, nor has any case yet been noticed of the spontaneous decomposition of the properly made and purified substance.

According to A. Brull, when, owing to the presence of free acid, decomposition does set in, it proceeds in a slow and tranquil manner, disengaging nitrous vapors, which color the liquid green, then developing nitrogen and carbon dioxide and crystals of oxalic acid, until, after some months, the entire mass is transformed into a greenish, gelatinous body composed of oxalic acid, water and ammonia. Sometimes, if the temperature is high, as when

heated by the sun, the decomposition is more active, but it by no means always leads to an explosion, though this must depend somewhat upon the quantity involved.

With ordinary care and the most common sense precautions, serious accidents resulting from the decomposition of large quantities of nitroglycerine may be prevented. As just stated, the primary cause of decomposition is the presence of free acid, which may be easily detected by the most ignorant person. Nitroglycerine may be conveniently stored in large earthen-ware crocks, which should be placed in copper buckets to catch any of the explosive which might by any chance escape from the crocks. When thus stored, the nitroglycerine should be covered with a layer of water, and by testing this water from time to time with litmus paper, the least development of acidity in the explosive is made known.

Should the nitroglycerine be stored in tin cans, by removing the caps and suspending the litmus paper immediately over the opening, any traces of acidity are at once discovered. In any case by hanging strips of litmus paper around the interior of the magazine, and examining them from time to time, a very approximate idea of the condition of the nitroglycerine can be formed. Should any slight acidity be developed and the means be at hand, the nitroglycerine should be thoroughly washed as already described. Should the litmus paper show strong acid reaction, and especially if any green color be developed in the explosive, it should be destroyed at once, the best way of doing this being to explode it in a safe place.

One very frequent source of accidental explosion results from gross carelessness in allowing cans or other vessels in which nitroglycerine has been stored to lie around loosely. In nearly every case, particles of the explosive adhere to the vessels, and oftentimes the verdict of "accidental death" should read "deliberate suicide." All such vessels should be destroyed immediately.

**The Explosive Force of Nitroglycerine.** Nitroglycerine is one of the strongest explosives in use; roughly speaking, it may be said to be eight times as powerful as gunpowder, weight for weight.

Nobel states that when nitroglycerine is completely exploded, it is resolved into carbon dioxide, water, nitrogen and oxygen, which may be represented as follows:



If we suppose that the substance be converted entirely into gas, it will have a constant volume of 22.32 litres at 0° C. and 76 cm., and a very simple calculation, based upon the above reaction, will show that 227 grammes of nitroglycerine yield 161.82 litres of gas under these conditions.

Berthelot gives the heat of combustion or calorific power of nitroglycerine as 356500 cal. Sarrau and Vieille obtained by actual experiment 360500 cal. The formula for determining the calorific intensity of a substance may be expressed as follows:

$$t = \frac{WC}{W_1S_1 + W_2S_2 + W_3S_3 + \&c.,}$$

in which

$t$  represents the calorific intensity,

$W$  represents the weight of the substance burned,

$C$  represents the calorific power of one gramme of the substance at 100° C.

$W_1, W_2, W_3$ , represent the weights of the products of combustion.

$S_1, S_2, S_3$ , represent the specific heats of the products of combustion.

Substituting now in this formula the lowest of the two numbers given above, and for  $W_1S_1, W_2S_2$ , etc., their values as follows:

$$\begin{array}{r} 132 \times .2169 = 28.63 \\ 45 \times .4805 = 24.63 \\ 42 \times .2438 = 10.24 \\ 8 \times .2175 = 1.74 \\ \hline 62.24 \end{array}$$

we have

$$t = \frac{356500}{62.24} = 5728^\circ$$

According to the law of Charles, the pressure remaining constant, the volume of any gas varies directly as its temperature on the \*Absolute Scale, or

$$V : V' :: T : T', \text{ or } V' = V \frac{T'}{T}$$

in which

V represents the original volume.

V' represents the new volume.

T represents the original temperature on the absolute scale.

T' represents the new temperature on the same scale.

Then

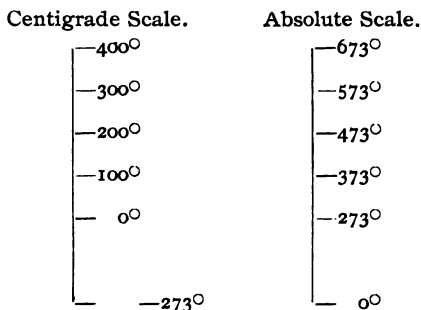
$$V' = \frac{161.82 \times 6001}{273} = 3557 \text{ litres,}$$

or one gramme of nitroglycerine will yield 15.7 litres. The density of nitroglycerine being 1.6, one cubic centimetre will weigh 1.6 grammes, and, therefore, one cubic centimetre will yield 25 litres of gas, and, the volume remaining constant, it will exert a pressure of 25,000 atmospheres or 164 tons per square inch.

The velocity of propagation of the explosive wave, when nitroglycerine is enclosed in tubes of 3 mm. in diameter, is, according to Berthelot, from 1078 to 1386 metres per second, it being 2333 to 2753 for dynamite and 5200 to 6000 for compressed pulverulent gun-cotton. This is remarkable, as it would seem that the highly elastic, nearly incompressible liquid ought to be the better conductor.

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\* Knowing the temperature on the Centigrade Scale, the corresponding temperature on the Absolute Scale is obtained by adding 273 to the degrees Centigrade. The relation between the two scales is shown in the following diagram :



**The use of Nitroglycerine in Blasting.** In spite of the many accidents that have occurred with it, nitroglycerine has been found to be so valuable that its use has steadily and largely increased. In difficult blasting where very violent effects are required, it surpasses all others. Its liquid form is a disadvantage, except under favorable circumstances, such as when at the place where it is to be employed. It, however, forms the essential ingredient in a number of solid mixtures, which will be considered later. When used in blasting or similar work it is usually put in tin cans or cartridge cases. A very good case may be made for it by rolling up stout brown paper into a cylinder of the desired diameter, gluing it, and fastening into one end a cork by choking with fine wire. When dry the case is soaked in melted paraffin. The fuse wires should pass snugly through a cork which fits the open end. This cork may be firmly fixed in the case by means of small tacks. If the bore holes are water-tight it may be poured directly into them, but it is rarely safe to do this, as there is great danger that some of it will escape through seams in the rock and not be exploded, remaining to cause accident at a future time. Since nitroglycerine is so readily detonated it has the advantage of not requiring strong confinement. Even when freely exposed it will exert violent effects such as breaking masses of rocks or blocks of iron. So, in blasting, it requires but little tamping. Loose sand or water is entirely sufficient. The relative force of nitroglycerine is not easily estimated, since the effect produced depends greatly on the attendant circumstances. Thus, a charge of nitroglycerine in wet sand or any soft material will exercise but a slight effect, while the same charge will shatter many tons of the hardest rock. In the former case much more sand would be thrown out by a slower explosion, which would gradually move it, than by the sudden violent shock of the nitroglycerine, which would only compress the material immediately about it. But in the hard rock the sudden explosion is much more effective than the same amount of force more slowly applied.

Nitroglycerine is now but little used in the free state, its principal use in this condition being for "shooting" oil wells, in order to free them from the paraffins with which they become clogged, or to shake the oil-bearing sandstones, so as to increase the yield.



The torpedoes used for this purpose consist of tin shells from three to five inches in diameter, and from five to twenty feet in length. These shells are taken to the well empty, the longer ones being in sections which are put together as they are inserted in the well. After the shells are inserted they are filled with the explosive, closed with a tightly-fitting cover to which a strong percussion cap is attached, and lowered to the bottom of the well (which is often 1500 feet or more in depth) by means of a wire. A perforated iron weight is then strung on the wire, and when the torpedo is in place it is exploded by allowing the iron weight to drop from the surface and strike upon the cap. An advantage which nitroglycerine possesses over gunpowder for use in mining is that in the liquid state it may be poured directly into the bore-hole, and that it may readily and easily be tamped by pouring water upon it, thus avoiding the dangerous process of tamping by ramming, which has given rise to many accidents and caused the loss of many lives. It is obvious, however, that liquid nitroglycerine can be used for this purpose only in holes which tend downwards, while in the operation of mining it is necessary to drive holes in every direction. This together with the fact already noticed that the liquid state made nitroglycerine a difficult substance to store, transport and use with safety, impressed the manufacturers with the necessity for devising some means by which it could be converted into such a solid state that the dangers noted could be avoided, while its great power and susceptibility to detonation could still be used at will. How this has been accomplished will be shown in the next lecture. It should be noted here, however, that a device employed by Nobel to render nitroglycerine insensitive, until desired for use, was by adding 15 to 20 per cent. of methyl alcohol to it. The two liquids were perfectly miscible, and the mixture was completely insensible to blows and even to detonation. When desired for use 6 to 8 volumes of water were added, which precipitated the nitroglycerine out unchanged. It can readily be seen, however, that this scheme was commercially impracticable.

**Tests for Nitroglycerine.** It is sometimes desirable to ascertain if a substance contains nitroglycerine, without undertaking

a complete analysis. Under such circumstances, the following simple tests may be applied :

If a liquid is oozing from a substance, or can be squeezed from it, put a drop of it on blotting paper. If it is nitroglycerine it will make a greasy spot, which will not disappear nor dry away upon standing ; struck with a hammer upon iron it explodes with a sharp report ; lighted, it burns with a yellowish to greenish flame, emitting a crackling sound ; and placed upon an iron plate and heated from beneath, it explodes sharply.

Again, introduce a few drops into a test tube and shake it up with a little methyl alcohol, which has been previously tested (by pouring a little of it into distilled water and seeing that it produces no turbidity). After shaking, filter the contents of the tube into a second test tube, and add a little distilled water to the latter. If the nitroglycerine is present, the liquid will become milky, and the nitroglycerine will eventually separate and collect at the bottom of the tube as a heavy lustrous liquid. A much more delicate test is with a solution of aniline and concentrated sulphuric acid as follows :

Aniline,	.	.	.	.	.	1 volume.
H <sub>2</sub> SO <sub>4</sub> (1.84),	.	.	.	.	.	40 "

Proceed as in the test just described with methyl alcohol, but, before adding the water, introduce into the tube a few drops of the aniline solution, which, if nitroglycerine be present, will produce a deep purple color. The color thus produced changes to green upon the addition of distilled water.

The tests for the condition of nitroglycerine as to stability, etc., do not differ materially from those described for gun-cotton.

**Test for the Presence of Free Acid.** Put 2.5 grammes in a thoroughly cleaned and dried test tube and add 10-20 c. c. of distilled water. Cork with a clean cork and shake the tube vigorously for two or three minutes and allow it to stand for a minute or two. Decant the supernatant liquid into a second tube which has been previously thoroughly cleaned, and test it with litmus paper.

**Stability or Heat Test for Nitroglycerine.** Precisely the same apparatus and methods are used as in the case of gun-cotton, with the following modifications: Five (5) grains of the explosive are used instead of twenty, and the time allowed for the appearance of the color on the test paper is reduced from fifteen (15) to ten (10) minutes. Great care must be taken in introducing the nitroglycerine into the tube so that the sides of the tube may not be soiled.

**Test for Nitrogen in Nitroglycerine.** This test is also performed with the same apparatus and in the same manner as the corresponding test for gun-cotton, which has already been described. In the case of tri-nitro-glycerine, having the formula  $C_3H_5O_3(NO_2)_3$ , the percentage of nitrogen should be 18.50. The ultimate analysis of compounds containing nitroglycerine will be considered subsequently.

## LECTURE XVI.

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### GUN-COTTON POWDERS AND DYNAMITES.

If we refer to the equation assumed to represent the reaction which occurred when the cellulose nitrate used by Karolyi in his experiments was exploded, or to the formula adopted by Vieille, we see that the products of explosion are those of incomplete combustion. The importance of this fact was quickly appreciated, and almost immediately suggested the practicability of devising an explosive which should be essentially gun-cotton, but in which the deficiency in oxygen should be supplied by the addition of oxidizing agents so as to obtain more complete combustion.

Several such mixtures have been prepared and have proved successful. In some cases, it has been found desirable to produce the explosive in a granular or some regular form, and cementing agents, such as gum, resin, paraffin, etc., have been added for this purpose, but such extraneous matter must be considered in the nature of an adulterant rather than as adding anything to the strength or explosive force of the mixture.

Some of the more important of these gun-cotton powders will be noted, but, on account of the difficulty of obtaining the exact proportions in which the several ingredients enter the commercial product, it will be necessary in some cases to give the theoretical instead of the practical powder.

**Tonite, or Tonite Powder.** This explosive was introduced into the United States in 1881, and has since that time been manufactured in large quantities under an English patent by the Tonite Powder Company of San Francisco. It consists of a mixture of pulverulent gun-cotton and barium nitrate, which theoretically should bear the relation of 60.28 parts of the former to 39.72 parts of the latter. Practically, standard tonite consists of

Gun-cotton,	. . . . .	52.5 parts.
Barium nitrate,	. . . . .	47.5 parts.

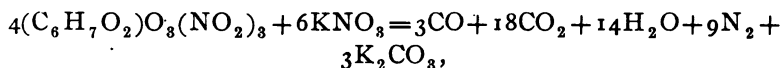
It is a whitish powder, and is generally put up in cartridges of from 3 to 12 ounces each, the cartridges being coated with paraffin to render them waterproof.

Tonite is as safe as the gun-cotton which forms its active principle; it is not at all sensitive to percussion, friction, etc.; does not explode upon the impact of the service rifle bullet, and requires an unusually strong detonator to cause an explosion, the full effect being developed by a special detonator made by the company, known as the "Tonite Cap." In several experiments, in which ordinary blasting caps (triple and quintuple force) were used, while no explosion occurred, the cartridge ignited and burned fiercely in the bore-hole until entirely consumed.

In storage, tonite seems to resist to a remarkable degree the extremes of climate. In strength, it stands to the gun-cotton from which it was made as 82 to 100.

In addition to tonite as described above and which is now known as *Cotton Powder No. 1*, there have been recently patented two other varieties, called *Cotton Powder No. 2* and *No. 3*, the former consisting of "gun-cotton thoroughly purified, mixed or impregnated with a nitrate or nitrates and charcoal," the latter of a "mixture of thoroughly purified meta-di-nitro-benzol, and thoroughly purified gun-cotton, mixed or incorporated with one or more of the following ingredients, namely, nitrate of potassium, nitrate of sodium, nitrate of barium, and chalk."

**Potentite.** This is a "nitrated gun-cotton" identical with tonite, except that potassium nitrate is substituted for the barium salt. If we assume the following reaction to represent what occurs when such a mixture is exploded, viz:



then the theoretical composition of potentite should be

Gun-cotton,	66.20 parts.
Potassium nitrate,	33.80 parts.

In practice, however, these proportions are changed somewhat, the amount of gun-cotton required by theory being reduced about 20 per cent.

**Abel's Gun-cotton Powder** was patented in 1867, and consists of gun-cotton mixed with a large proportion of an oxidizing body, such as potassium chlorate or nitrate, or sodium nitrate, or mixtures thereof, with an addition of a small proportion of alkali, or of an alkaline carbonate. The patentee recommended the following proportions:

Gun-cotton,	70 to 40 parts.
Oxidizing substances,	29 to 59 "
Alkaline substances,	1 "

*Bantock's gun-cotton powder* is essentially the same as that just described, with the addition of a neutral salt.

**E. C. Powders.** These powders consist of rifle, or pulverulent gun-cotton, and are divided into two classes, *Sporting Powder*, in which the gun-cotton is dissolved in ether, alcohol and benzoline, and the product colored a deep orange tint by the addition of aurine; and *Rifle Powder*, in which the same solvent is used, but the color (straw yellow) is derived from picric acid. Both powders are carefully granulated, and an analysis of two samples gave:

	I.	II.
Nitro-cellulose, soluble,	27.95	21.79
Nitro-cellulose, insoluble,	27.35	25.58
Cellulose, unconverted,	3.15	4.17
Potassium and barium nitrates,	37.80	38.32
Substances soluble in benzole,	0.60	1.95
Substances soluble in alcohol,	2.15	6.32
Moisture,		1.87

**Johnson's Powders** deserve notice under the head of gun-cotton powders. In these powders di-nitro-cellulose or lower forms of cellulose are employed, impregnated with barium or potassium nitrates and incorporated with charcoal or other carbonaceous material. Two samples given in the specification consisted of

For Military Arms.      For Sporting Arms.

Nitro-cellulose,	50 parts.	50 parts.
Potassium nitrate,	40 parts.	22 "
Barium nitrate,	—	25 "
Lamp-black,	10 parts.	3 "

The powders are granulated and impregnated with a solution of camphor and phenol, or camphor alone, in a suitable volatile solvent, in the proportion of one part of camphor (or camphor and phenol) to five parts of solvent to ten parts of the powder. Both solvent and camphor are driven off at a gentle heat. It is claimed that by this method powders can be produced of any required degree of hardness and density, thereby regulating the energy of action of the explosive, and it is stated that "these results are obtained not by the presence of camphor in large or small quantities in the finished explosive, but by a remarkable gelatinizing and perhaps some other actions exerted by the camphor upon the nitro-cellulose when these are heated together at varying temperatures up to 100° C., whereby the hardness and density of the explosive may be regulated at will by the proportion of camphor used." The use of ordinary gun-cotton in these powders is especially barred on account of the elements of uncertainty and danger introduced by it. According to the specifications, the resulting powders are evidently nitrated celluloids.

Professor Munroe in his lectures makes a distinction between these gun-cotton powders and another and very closely allied class of explosives which are derived from nitrating cellulose obtained from wood and similar materials. To this last class of explosives he gives the name *Nitro-lignin Powders*. A single sample will illustrate the principle involved in all such powders.

**Schultze Gunpowder** consists of nitro-lignin mixed with a nitrate or nitrates (other than the nitrate of lead), and with or without starch or collodion (consisting of nitro-lignin dissolved in ether and alcohol) or solid paraffin free from mineral acid. Analysis of a sample of this powder gave:

Soluble nitro-lignin, . . . .	24.83 parts.
Insoluble nitro-lignin, . . . .	23.36 "
Lignin, unconverted, . . . .	13.14 "
Potassium and barium nitrates, . . . .	32.35 "
Paraffin, . . . . .	3.65 "
Matters soluble in alcohol, . . . .	0.11 "
Moisture, . . . . .	2.56 "

The advantages claimed for these powders are that they generate but little smoke, impart but a slight recoil, produce a mild report, and leave little or no residuum to foul the piece. Although many of the powders have been used for sporting purposes, they have, unfortunately, developed at times such abnormal pressures as to burst the piece. Moreover the conditions under which these accidents have occurred in the past are more likely to obtain in great guns than in fowling pieces, and during an engagement when the pieces are fired more rapidly and become greatly heated than in fowling pieces which are discharged at intervals and remain cool.

**Dynamite.** On account of the many disadvantages attending the handling, storage and transportation of liquid nitroglycerine, efforts were made soon after the discovery of this explosive, in which it was sought to neutralize these dangers. In 1866 Nobel perfected his invention and in the following year *dynamite* appeared for the first time in a commercial form. In the English patent, the inventor describes his new production as follows: "This invention relates to the use of nitroglycerine in an altered condition, which renders it far more practical and safe for use. This altered condition of the nitroglycerine is effected by causing it to be absorbed in porous inexplusive substances, such as charcoal, silica, paper, or similar materials, whereby it is converted into a powder, which I call dynamite, or Nobel's Safety Powder." By the absorption of the nitroglycerine in some porous substance it acquires the property of being in a high degree insensible to shocks, and it can also be burned over fire without exploding. It is evident that in thus absorbing the nitroglycerine in a solid material, the explosive is not converted into a solid, but is merely retained in the pores of the absorbent through the force of capilarity.

The commercial success attending the invention of Nobel naturally led others to follow where he had led and to examine the suitability of various materials as absorbents, and within an incredibly short period, the market was flooded with dynamite under a great variety of names.



According to the nature of the material used as the absorbent (or as it is now technically known, the *dope*), dynamites may be conveniently divided into

1. *Dynamites with an Inert Base.*

2. *Dynamites with an Active Base.*

**Dynamites with an Inert Base.** The well-known action of porous and finely divided solids towards liquids probably led Nobel to adopt in his earliest experiments the substance which was probably best suited for use as a purely inert absorbent. *Kieselguhr* is a substance which is familiar to all under the names of "tripoli" or "rotten-stone," and possesses in a marked degree high absorptive power. This property together with the tenacity with which it retained the liquid explosive under considerable changes of temperature; its great chemical stability, and entire inability to react with nitroglycerine; its abundance and consequent cheapness, all combined to recommend it to the inventor.

Kieselguhr is now known to consist of the inorganic remains of countless millions of extremely minute inorganic beings called infusoria or diatoms.

Enormous deposits of this infusorial or diatomaceous silica are to be found near Oberlohe in Hanover, and in this country a large deposit has been traced from Herring's Bay in Maryland to a point beyond Petersburg, Virginia; Richmond resting upon a deposit which is 20 feet deep.

When found it is more or less contaminated with impurities, and it has to be calcined to get rid of the organic matter. The reddish tinge often observed in dynamite is due to a little iron contained in the kieselguhr.

In a pure and dry condition, kieselguhr will absorb three times its weight of nitroglycerine, and will retain it even at the highest ordinary temperature.

**Dynamite No. 1.** This explosive, now known as *Kieselguhr Dynamite No. 1*, is essentially a mixture of one part of kieselguhr and three parts of nitroglycerine. To transform liquid nitroglycerine into dynamite No. 1, it is only necessary to place in a non-porous vessel one part by weight of the absorbent and pour upon it three parts by weight of nitroglycerine, mixing the two gradually with a wooden spatula. In a few moments the liquid

will disappear, and in its place we will have a plastic mass which is scarcely moist to the touch. It has been seen that nitroglycerine, even when thoroughly washed, has a tendency to develop traces of acid during storage or exposure, and in order to eliminate this possible source of danger, it is usual in the manufacture of dynamite to add a small amount of an alkaline carbonate to neutralize any acidity that may be developed.

The principle of dynamite is very simple. The absorbent is perfectly inert, adds nothing to the strength of the explosive, and is rather to be considered an adulterant; but, on the other hand, by transforming the incompressible liquid into a compressible solid, it produces an explosive which is much less sensitive to blows, and which is therefore safer. Its sensitiveness to blows, however, increases very rapidly with the temperature, so that, according to Eissler, "at 350° F., the fall upon it of a dime will explode it."

Dynamite No. 1 is a granular substance having a pearl-gray to reddish-brown color, and a plastic consistency similar to that of brown sugar. Its density varies from 1.5 to 1.6. The firing point of dynamite is about 180° C. (356° F.), and at this temperature it either burns or explodes; if free from all pressure, jar, vibration, or force of any kind, it burns; otherwise it explodes. When heated to a temperature less than this, it is exploded by a detonator more or less readily depending upon the degree of heat to which it has been subjected and the time of such exposure.

When ignited in small quantities in the open air, it simply burns fiercely, but when large amounts are ignited, explosion almost invariably results, the explanation being obvious. High temperatures below the firing point causes dynamite "to leak," as it is technically expressed, or causes the nitroglycerine to exude, hence a dynamite should always be carefully tested and made to resist exudation at the highest temperature to which it may be exposed.

Dynamite freezes at about 4° C. (40° F.), and when once frozen it remains in this condition at temperatures considerably exceeding this. Solidly frozen, it cannot be detonated except with great difficulty, but if loose and pulverulent it may be detonated, although its force is much diminished. In practice therefore it is

customary to thaw the frozen explosive before using it. This operation requires great care, and it is very easily performed, yet the great number of fatal accidents which have resulted either through ignorance or criminal neglect or total disregard of the instructions issued with each package of the explosive as to how to perform the operation, has served in a great measure to prejudice the popular mind against dynamite. In each and every case the accident can be traced to the responsible person or persons, and a few criminal proceedings in this country such as invariably follow such "murders" or "suicides" in England would have a very wholesome effect.

These accidents are generally due to the erroneous supposition that because it is reasonably safe to ignite a cartridge of unfrozen dynamite, it is equally safe to warm it upon a shovel, or in a tin can, or in an oven; whereas, when heated in this manner, the danger limit is approached with each succeeding degree of temperature. *All nitroglycerine preparations, when gradually heated up to their exploding points, become extremely sensitive to the least shock or blow,* and once that point is reached, they no longer simply ignite, but explode with great violence; and further, owing to the poor conductivity of the material, a small portion of dynamite in contact with the source of heat may reach this point and cause the explosion of the rest of the mass, which may be considerably below the danger point.

The best way to thaw dynamite is to open the package and place it in a room where the temperature does not exceed 212° F., and allow the explosive to thaw gradually.

The next best way is to place the cartridges in a water-tight can (tin or copper) and place this can inside of another vessel containing boiling hot (not boiling) water. By covering both vessels with a cloth, the cartridges will be thawed quickly. By no means should an attempt be made to thaw any form of dynamite by placing it in the vicinity of a hot fire, nor by placing it directly on a hot plate or shovel, nor by leaning it up against hot brick-work or steam boilers; in short in any other way than that described above. As is to be expected from what has been said, dynamite may be exploded by the impact of a rifle bullet, and this too whether frozen or unfrozen, and while it is much less

sensitive to such a blow when frozen than when unfrozen, it is much more susceptible to explosion by ignition in the former condition than in the latter.

Very soon after the introduction of dynamite, it was discovered that one of the very properties of the new explosive by virtue of which its inventor claimed for it superiority over all other blasting agents, namely, its tremendous power, rendered it wholly unfit for certain kinds of work such as mining coal, quarrying rock for building purposes, etc. In all such work, as also in working in soft coal and earth, Dynamite No. 1 was found to be less efficient than black powder. As the energy of the explosive was entirely dependent upon the nitroglycerine contained in it, it was a very simple problem to regulate its force. To reduce this energy and moderate the violence of the explosion, it was only necessary to reduce the percentage of nitroglycerine in the dynamite. Experience has proven this to be true, but only up to a certain point so far as it concerns Dynamite No. 1, since it is claimed that a kieselguhr dynamite containing less than 30 per cent. of nitroglycerine cannot be exploded.

In the case of dynamites having active bases, however, the proportion of nitroglycerine may be reduced to less than five per cent., and the resulting explosive still be susceptible of explosion. In commerce dynamite is generally found put up in stout paper cartridge cases which are coated with paraffin to render them impervious to moisture.

**Dynamite with an Active Base.** Dynamites with active bases may be subdivided into three classes according as the base is

1. *A combustible* merely, as charcoal; or
  2. *An explosive mixture*, whether of the nitrate or chlorate class;
- or
3. *An explosive compound.*

The principle involved in these powders is to substitute for the perfectly inert base of ordinary dynamite, an absorbent which will not only retain the nitroglycerine, but, by its own combustion or explosion, contribute to the explosive effect of the powder.

**Dynamite with a Combustible Base—Carbo-dynamite.** As an example of this class, carbo-dynamite may be mentioned as one of the most recently patented and most favorably received. It

consists of 90 parts or less of nitroglycerine and 10 parts of very absorbent charcoal, obtained by carbonizing cork. To every 100 parts of the explosive is added 1.5 parts of sodium or ammonium carbonate. In one variety water is added with the view of rendering the dynamite unflammable. This explosive does not disintegrate or "leak" when exposed to the action of water. It is a black somewhat friable substance, and compares very well with other dynamites of the same grade.

Another explosive of this class very similar to carbo-dynamite is *Punshon's Explosive*, in which 30 parts of carbonized or charred peat are used to absorb 70 parts of nitroglycerine. In the preparation of the explosive, the nitroglycerine "is cleaned by means of chalk mixed with water instead of by the use of alkalies."

**Dynamite with an Explosive Mixture Base.** As already indicated, dynamites of this class may be further subdivided according as the base is a *nitrate* or *chlorate* mixture.

**Dynamite with a Nitrate Mixture Base.** One of the simplest and earliest powders of this class consisted of a mixture of nitroglycerine and mealed gunpowder. In addition to the increased safety of the powder over that of nitroglycerine in a liquid state, it was claimed that the new powder was much more powerful than ordinary dynamite, and that the power actually developed was considerably greater than the sum of the forces of the two ingredients fired separately. In explanation and support of this claim, the inventor asserted that when fired the gunpowder was detonated by the nitroglycerine, it being well known that the force developed by gunpowder when detonated is something greater than four times that observed when it is simply exploded. This particular powder was followed by others too numerous to be mentioned. The composition of some of the better known dynamites of this class are given below.

**Dynamite No. 2.** This explosive was introduced to compete with powders ordinarily used where great power and local effect was not desired, such as for work in coal mines, etc. It consists of

Nitroglycerine,	. . . . .	18 parts.
Potassium nitrate,	. . . . .	71 "
Charcoal,	. . . . .	10 "
Paraffin,	. . . . .	1 "

**Giant Powder No. 2** is practically the same as dynamite No. 2, consisting of

Nitroglycerine, . . . . .	40 parts.
Potassium (or sodium) nitrate, . . . . .	40 "
Sulphur, . . . . .	6 "
Rosin, . . . . .	8 "
Kieselguhr, . . . . .	8 "

This powder is manufactured in various grades, the percentage of nitroglycerine varying from 75 to 20 per cent.

**Judson Powder** as manufactured in this country consists of

Nitroglycerine, . . . . .	5 parts.
Sodium nitrate, . . . . .	64 "
Sulphur, . . . . .	16 "
Cannel coal, . . . . .	15 "

These proportions refer to one of four grades of the powder and is known commercially as the R. R. P. grade.

**Vulcan Powder** consists of

Nitroglycerine, . . . . .	32.60 parts.
Sodium nitrate, . . . . .	49.46 "
Sulphur, . . . . .	8.31 "
Charcoal, . . . . .	9.63 "

**Neptune Powder**, manufactured by the same company, is identically the same explosive as that just described, the proportions of the ingredients varying slightly.

**Atlas Powder** is one of the best known dynamites in this country, being manufactured in nine different grades, the percentage of nitroglycerine varying from 20 to 75 per cent.

*Atlas A* consists of

Nitroglycerine, . . . . .	75 parts.
Sodium nitrate, . . . . .	2 "
Magnesium carbonate, . . . . .	2 "
Wood fibre, . . . . .	21 "

*Atlas B* consists of

Nitroglycerine, . . . . .	50 parts.
Sodium nitrate, . . . . .	34 "
Magnesium carbonate, . . . . .	2 "
Wood fibre, . . . . .	14 "

*Dualin* consists of

Nitroglycerine, . . . . .	50 parts.
Potassium nitrate, . . . . .	20 "
Fine sawdust, . . . . .	30 "

**Rendrock** is essentially the same as *dualin* with the addition of seven parts of paraffin.

**Dynamite with a Chlorate Mixture Base.** In these powders potassium chlorate alone or mixed with the nitrate is used to furnish the additional force.

**Hercules Powder** is such an explosive, although at least one grade of it (No. 1 Extra) consists of nearly 80 per cent. of nitroglycerine and 20 per cent. of magnesia alba. It is made in several grades, one being constituted as follows:

Nitroglycerine, . . . . .	40.00 parts.
Potassium chlorate, . . . . .	3.34 "
Potassium nitrate, . . . . .	31.00 "
Magnesium carbonate, . . . . .	10.00 "
White sugar, . . . . .	15.66 "

**Horsley's Powders** afford more striking examples of this class. Two varieties licensed some years ago consisted of

	A	B
Nitroglycerine, . . . . .	76 parts.	72 parts.
Potassium chlorate, . . . . .	3 "	6 "
Nutgalls, . . . . .	1 "	1 "
Wood charcoal, . . . . .		1 "

**Vigorite.** One brand of this powder manufactured by the California Vigorite Powder Co. consists of

Nitroglycerine, . . . . .	43.75 parts.
Potassium chlorate, . . . . .	17.50 "
Potassium nitrate . . . . .	18.75 "
Sawdust, . . . . .	11.25 "
Chalk, . . . . .	8.75 "

Table showing the percentage of nitroglycerine contained in the various grades of the dynamites described, together with the trade designations of the several grades.

ATLAS. (Standard.)		HERCULES.		GIANT.	
BRAND.	PER CT. N. G.	BRAND.	PER CT. N. G.	BRAND.	PER CENT. N. G.
.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	Extra .....	20
E .....	20	No. 4.....	20	M.....	20
.....	.....	.....	.....	F. F. F. F.....	20
E+ .....	27	No. 4 S.....	27	XXX.....	27
D .....	30	.....	.....	.....	.....
D+ .....	33	No. 3 S.....	33	No. 2 C.....	33
.....	.....	.....	.....	.....	.....
C .....	40	No. 2.....	40	No. 2.....	40
C+ .....	45	No. 2 S.....	45	No. 2 Extra.....	45
B .....	50	No. 2 SS.....	50	New No. 1.....	50
B+ .....	60	No. 1.....	60	.....	.....
A .....	75	No. 1XXX.....	75	No. 1.....	75

ÆTNA.		HECLA.		JUDSON.	
BRAND.	PER CT. N. G.	BRAND.	PER CT. N. G.	BRAND.	PER CENT. N. G.
.....	.....	.....	.....	R. R. P.....	50
.....	.....	.....	.....	F.....	10
No. 5.....	15	.....	.....	F. F.....	15
No. 4.....	20	No. 3.....	20	F. F. F.....	20
No. 4X.....	25	.....	.....	.....	.....
No. 3 B.....	27	No. 3X.....	27	Dbl. Ex.....	27
No. 3.....	30	No. 2.....	30	.....	.....
No. 3 A.....	33	No. 2X.....	33	Trpl. Ex.....	33
No. 3X.....	35	.....	.....	.....	.....
No. 2.....	40	No. 1.....	40	.....	.....
No. 2X.....	45	.....	.....	.....	.....
No. 2XX.....	50	No. 1X.....	50	.....	.....
No. 1.....	60	No. 1XX.....	75	.....	.....

All of the dynamites so far enumerated possess in a more or less degree the properties attributed to Dynamite No. 1. All of



them when ignited in small quantities and unconfined burn harmlessly, but when confined or heated gradually to their points of ignition they become dangerously sensitive to the slightest disturbing cause. Nearly all of them are more or less sensitive to percussion and friction, but when intelligently handled, they may be said to be fully as safe as ordinary gunpowder.

**Dynamite with an Explosive Compound Base.** To be perfectly logical in treating the subject of dynamite, this class should be subdivided according as the absorbent or base is a *nitro-substitution compound* or a *nitric ester*.

**Castellano's Powder.** Under the first subdivision would be found two varieties of this explosive, the first consisting of a mixture of nitroglycerine, nitro-benzol, fibrous material and pulverized earth. The second variety consists of nitroglycerine, potassium or sodium nitrate, an insoluble salt, carbon, sulphur and a picrate. The insoluble (and incombustible) salt may be a silicate of zinc, magnesia or lime, oxalate of lime, carbonate of zinc, etc. The following proportions have been suggested for the mixture:

Nitroglycerine,	. . . . .	40 parts.
Sodium nitrate,	. . . . .	25 "
Insoluble salt,	. . . . .	10 "
Carbon,	. . . . .	10 "
Sulphur,	. . . . .	5 "
Picrate,	. . . . .	10 "

Under the second subdivision would be found the long list of gelatine dynamites, or gum dynamites.

The theory upon which these explosives are formed is readily understood. If we examine the equations supposed to represent the reactions which occur upon the explosion of nitroglycerine and gun-cotton respectively, it will be seen that when nitroglycerine is detonated free oxygen is evolved, while when gun-cotton is detonated we have a product of incomplete combustion in the form of carbon monoxide. If therefore these two explosives can be so combined as to use the excess of oxygen in the one to produce complete combustion in the other, we should have theoretically a far more powerful explosive than either of the constituents alone.

**Explosive Gelatine.** As a matter of fact, however, these proportions are realized only in Nobel's *Explosive Gelatine*, or as it is sometimes called, *Gum Dynamite*. This substance is made by dissolving soluble gun-cotton in nitroglycerine by the aid of heat, and, when the solution is complete, allowing the mass to cool. The product solidifies to a gelatinous paste which has a honey yellow color and a consistency varying from that of tough leather to that of ordinary jelly, this difference being due to the chemical condition and amount of the cellulose nitrate, as well as the mode of manufacture pursued. The percentage of cellulose nitrate usually varies from 4 to 8 per cent. As prepared in the laboratory, the nitroglycerine is placed in a well-annealed glass vessel (or one of metal) which is suspended in a water bath, and the water heated gradually to a temperature not exceeding 160° F. The cellulose nitrate, thoroughly washed and purified, and as finely divided as possible, is gradually added with constant stirring, each charge of the nitrate being completely dissolved before another is added.

Thus prepared, explosive gelatine has a specific gravity of 1.6. It does not absorb water, and, when placed in it, it is affected only superficially, a very small quantity of nitroglycerine being dissolved from the surface which assumes a whitish color, but no further change occurs, no matter how long the explosive remains immersed.

Unconfined it burns, when ignited, with a bright yellow flame and a hissing sound, but does not explode. If, however, it is confined and heated to its ignition point, it explodes violently. Heated slowly it explodes at 204° C. (399° F.); heated rapidly it explodes at 240° C. (464° F.) At low temperatures it freezes into a hard solid of paler yellow color than when in its normal state, and seems to assume a crystalline structure.

The exact temperature at which it freezes has not been definitely ascertained, as some cartridges have been found to resist freezing when exposed to a freezing mixture for twenty-four hours, while others have frozen readily at 2° to 4° C. (35° to 40° F.) Unlike several dynamites previously considered, explosive

gelatine is much more sensitive when frozen than when in the unfrozen state, and can be readily detonated or exploded by the impact of bullets.

The sensitiveness of this explosive is greatly diminished by the addition of camphor, or other substances rich in carbon and hydrogen, such as benzene. These substances are soluble in nitroglycerine and may be readily introduced during the process of manufacture.

**Military Explosive Gelatine** is such a mixture containing about four per cent. of camphor. In appearance it is similar to ordinary explosive gelatine, but it emits the odor of camphor, and with the exception of the increased insensitiveness its properties are the same.

Berthelot holds that the effect of the camphor, in increasing the insensitiveness of the explosive, results from the increased elasticity and solidity which the explosive thus acquires, in consequence of which the initial shock of the detonator is propagated through a much greater mass of the substance than it would be if the camphor were not present, so that the sudden and local elevation of the temperature, which is necessary for the chemical and mechanical action which results in detonation, is not realized except by the use of a very powerful detonator. Camphor, according to this theory, does not exert any action on discontinuous powders, and this is shown in practice with potassium chlorate powders.

On account of its solid form and plastic nature, its great power and insensitiveness, explosive gelatine has been regarded as the ideal military explosive, but, unfortunately, it has in several instances decomposed during storage, and without any apparent cause. One such case of decomposition is recorded by Professor Munroe, of the U. S. Naval Torpedo Station, and others have been noted, although no explosions resulted. At the Artillery School, a package containing fifty pounds was subjected to considerable variations of temperature for six years, and on one occasion was immersed in sea water for four days, and when samples

were subjected to service tests, no signs of decomposition were discovered, while, tested in the pressure gauge, it showed most conclusively that it had lost none of its explosive force.

Berthelot finds the theoretical pressure of this explosive to be nearly identical with that of nitroglycerine. F. von Rziha finds its theoretical efficiency to be less than that of nitroglycerine in the ratio of 1.40 to 1.45, and, from the discussion of extensive data practically obtained, he supports his conclusion.

General Abbot, however, finds the relative intensity of Dynamite No. 1, nitroglycerine and explosive gelatine, when fired under water to be as 100 : 81 : 117; and with a sample of explosive gelatine furnished by Nobel's Explosive Company of Glasgow, he obtained a relative intensity of 142.

In the experiments with the Quinan Pressure Gauge, conducted at the Artillery School, these intensities were as 81.31 : 81.85 : 106.17.

**Gelatine Dynamite.** This explosive, as its name signifies, stands midway between the explosive gelatine just described and dynamite, and consists of a thin blasting gelatine mixed with other substances. Two varieties are generally known; No. 1 consists of a thin gelatine mixed with cotton, charcoal, or similar substances. No. 2 consists of No. 1 incorporated with potassium or other nitrates. They resemble explosive gelatine so closely that it is very difficult to distinguish them by appearance alone. One grade containing 60 per cent. of blasting gelatine has been dignified by a separate name—*Gelignite*.

**Forcite.** In this country, gelatine dynamite is patented under the name of *Forcite*. The American patent for this explosive describes it as a combination of nitroglycerine with "an inexplusive gelatinizing material and an oxidizing salt." Analysis of samples of forcite, however, showed that it consisted of a thin blasting gelatine with which were incorporated potassium nitrate, wood pulp, and a little dextrine; practically it was a gelatine dynamite containing dextrine. According to the particular grade, forcite contains from 30 to 97 per cent. of nitroglycerine, while the proportions of the other ingredients are given as follows:

Potassium nitrate,	. . . . .	77 parts.
Wood tar,	. . . . .	20 "
Sulphur,	. . . . .	3 "
Wood pulp,	. . . . .	1 "

It is claimed that the pulp counteracts the sticky qualities of the tar, which in turn prevents the thin gelatine from soaking in, thereby acting as a carrier rather than as an absorbent. According to General Abbot, this explosive is the strongest in the American market, developing an intensity of 133 per cent.

**Ecrasite.** This is supposed to be a composition of blasting gelatine treated with the sulphate or hydro-chlorate of ammonia, or both, and is reported as being adapted for use in small arm cartridges. Extensive trials of this explosive have been made in Austria, and the effects produced are stated to be similar to those produced by mélinite. It is said to be very powerful, and in no way sensitive to mechanical and atmospheric influences, and is considered a valuable explosive for military purposes.

**Tests for Dynamite.** Generally speaking the tests for various dynamites, except in the case of actual analysis, consist in the determination of the quality of the nitroglycerine which forms the active principle of the explosive.

**Separation of the Nitroglycerine from the Base.** In order to test the nitroglycerine, it is first necessary to separate it from the base, and this is done as follows :

About 25 grammes of the dynamite are placed in a glass funnel which has previously been thoroughly cleaned and plugged with asbestos. The surface is smoothed with a flat-headed glass rod, and kieselguhr, clean and dried, spread over it to the depth of about one-eighth of an inch. Water is next added until the layer of kieselguhr is thoroughly moistened, and a clean, dry test tube is placed under the funnel to catch the nitroglycerine. Water is added from time to time until sufficient nitroglycerine is collected for the several tests. If any water passes through with the nitroglycerine, it is removed with a piece of blotting paper, or, if necessary, the nitroglycerine is filtered through a dry filter.

**Test for Free Acid in Dynamite.** For this test, it is not absolutely necessary that the nitroglycerine be separated, but if that

has been done, proceed exactly as in the test for ordinary nitroglycerine. Generally it is only necessary to put about one gramme of the explosive in a perfectly clean test tube, and half fill the tube with distilled water. The tube is then closed with the thumb and shaken vigorously for two or three minutes. As soon as the dynamite settles to the bottom of the tube, the water is tested for acidity in the usual way.

**Stability and Nitrogen Tests for Dynamite.** These tests are conducted in precisely the same manner as has already been described for nitroglycerine, the sample to be tested being taken from the nitroglycerine which has been separated from the base as above indicated.

**Stability Test for Explosive Gelatine.** In the case of explosive gelatine, it is necessary to especially prepare the explosive before subjecting it to the Heat or Stability Test.

About one and one-half grammes of the gelatine are incorporated with twice the quantity of French chalk by working them together gently in a porcelain dish with a wooden spatula.

When intimately mixed, enough of the mixture is introduced carefully into the test tube, so that when it is gently compressed, it will fill the tube to the depth of about  $1\frac{3}{4}$  inches.

The rest of the test is conducted as already described, except that the temperature of the bath is kept at  $160^{\circ}$  F., and the time allowed before discoloration of the test paper appears is 10 minutes.

**Liquefaction Test for Explosive Gelatine.** In addition to the usual tests to which all nitroglycerine preparations are subjected, there is an additional test which is applied to explosive gelatine known as the *liquefaction test*. To make this test, a cylinder is cut from a gelatine cartridge or stick, the length of which is equal to its diameter, the ends being perfectly flat. The cylinder is then secured to a perfectly flat surface by means of a pin passing vertically through its centre, and exposed to a temperature from  $85^{\circ}$  to  $90^{\circ}$  F. for six days and nights (144 hours). During such exposure, the cylinder should not diminish more than one-fourth of its original length, and the upper cut surface should retain its flatness and the sharpness of its edge.

*The test of liability to exudation* of gelatine requires that there shall be no separation of the general mass of the sample to be

tested of a substance of less consistency than the bulk of the remaining portion of the material under any condition of storage, transport, or use, or when the material is subjected three times in succession to alternate freezing and thawing, or when subjected to the liquefaction test hereinbefore described.

In addition to these tests for dynamite, which are readily made and require no particular knowledge of the chemical principles involved, it is sometimes necessary to determine more fully, not only qualitatively, but quantitatively, the character of nitroglycerine preparations.

The following outline scheme of analysis will indicate the method to be pursued.

#### Outline Scheme for the Analysis of Nitroglycerine Preparations.

I. Exhaust the previously dried substance with anhydrous ether, preferably in a fat extraction apparatus. (1 and 2.)

1. *Solution*: divide into two equal parts. (A and B).

**A.** Allow the ether to evaporate spontaneously, dry the residue in a vacuum of  $H_2SO_4$ , and weigh.  
Weight represents nitroglycerine, resin, camphor<sup>1</sup>, (sulphur<sup>2</sup>) and paraffin.

**B.** Add phenolphthalein and titrate with alcoholic potash (1 c.c. N-KHO = 0.330 resin). Add considerably more K HO; evaporate, dissolve the residue in water, shake with ether, and separate.

1. Determine the camphor by difference.
2. As sulphur is very sparingly soluble in ether, it is preferable to extract some of the original substance with water, and treat the residue with alcoholic potash, add Bromine, acidify and precipitate as  $BaSO_4$ .

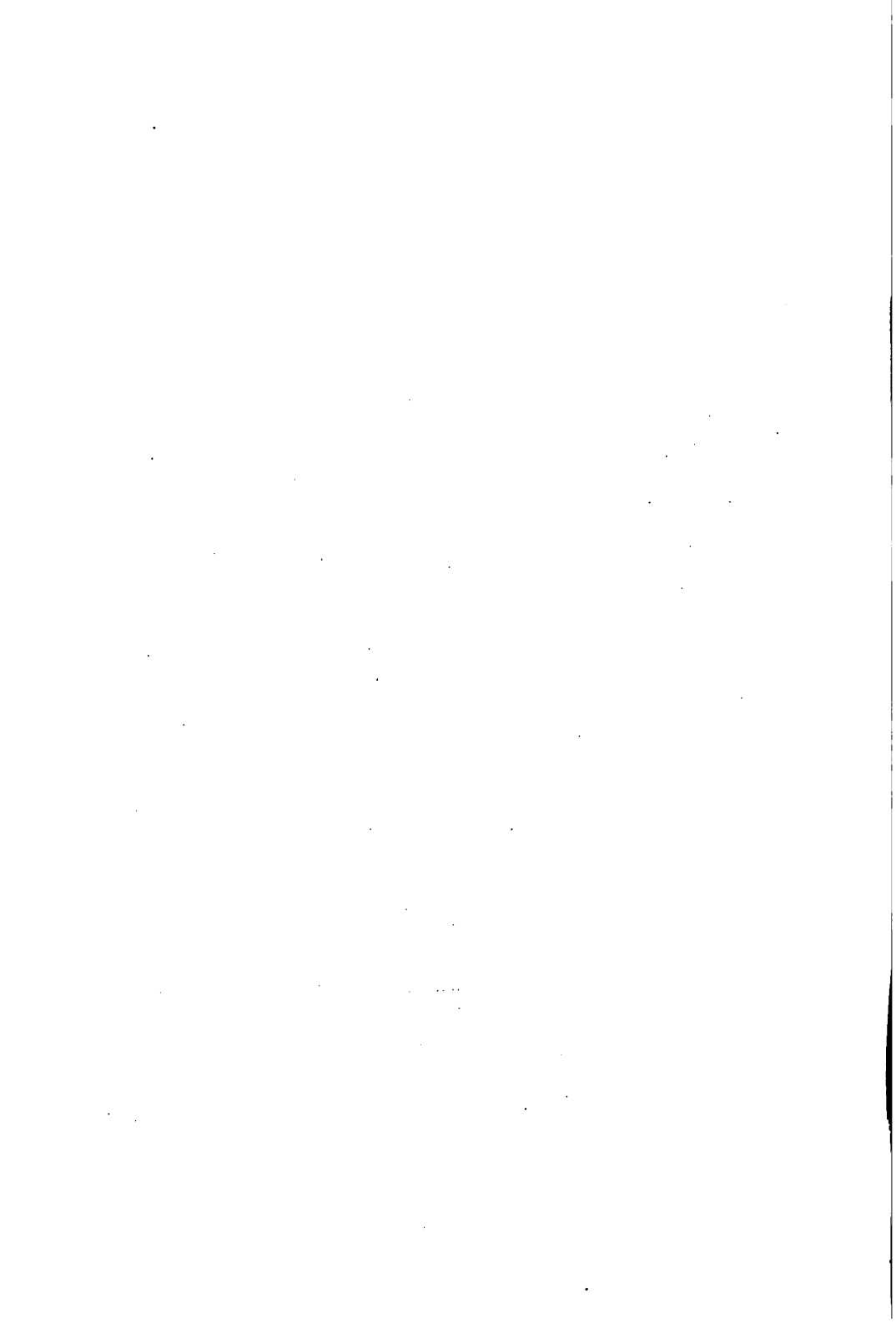
Ethereal Solution.	Aqueous Liquid.
Evaporated, leaves the paraffin.	Add Bromine, and acidify with HCl. Separate <sup>1</sup> the resin, and precipitate with $BaCl_2$ . Ignite and weigh for sulphur. 1. By filtration.

2. *Residue*: dry, weigh, and exhaust with water in an extraction apparatus. (C and D).

C. <i>Solution</i> :	D. <i>Residue</i> :
Contains metals, nitrates, chlorates, soluble carbonates, etc., the sum of which (except $(\text{N-H}_4)_2\text{CO}_3$ ) can be determined by evaporating the solution to dryness at $100^\circ\text{C}$ , and weighing the residue. The nitrates can be conveniently determined by a nitrometer.	Dry, weigh and agitate aliquot part with $\text{H}_2\text{SO}_4$ and Hg in a nitrometer. Evolved gas = $\text{N}_2\text{O}_2$ for cellulose nitrates. If any $\text{N}_2\text{O}_4$ is evolved, treat the remaining part of residue with a mixture of 2 parts of ether and 1 part of absolute alcohol. (E and F).
E. <i>Solution</i> :	F. <i>Residue</i> :
Evaporate and weigh the residue, which consists of mono and di-nitro-cellulose, and collodion gun-cotton. This may be further examined by the nitrometer.	Dry, weigh and treat a weighed portion in nitrometer, calculating evolved gas to tri-nitro-cellulose. If present, exhaust the remaining part of residue with acetic ether. (G and H).
G. <i>Solution</i> :	H. <i>Residue</i> :
Contains tri-nitro-cellulose.	Weigh, ignite, and weigh again. Loss of weight represents sawdust, cellulose of Kieselguhr, charcoal, chalk and other mineral matter.

In this lecture, no effort has been made to enumerate the practically limitless list of cotton powders and dynamites, but merely to classify them and illustrate each class by some of the better known and more reliable explosives.





## LECTURE XVII.

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### SMOKELESS POWDERS.

All of the so-called *smokeless powders* may be classified under one or another of the classes of explosives already enumerated, but on account of the wide-spread attention that this subject has attracted during the past five years, it is deemed advisable to consider these new substances separately.

Incidentally it may be stated that the necessity for such powders was created by the development of the full power of the magazine rifle and the machine and rapid-fire guns, and although it may be safely asserted that as yet no such powder has been invented as will probably stand the test of service, it may with equal certainty be prophesied that the present difficulties will be overcome, and that the new compound, or mixture will supersede the old black powder, at least, for all military purposes.

The ancient claim of comparative smokelessness made for Schultze's Powders was absurd on its very face, the presence of the nitrates of barium and potassium in their composition proclaiming beforehand very appreciable volumes of white smoke, consisting of the carbonates of those metals, upon explosion of the powders. At the present time, Schultze's powders are interesting only as early examples of nitro-cellulose powders.

The smokeless powders recently experimented with may be divided into three general classes, viz :

- 1st. *Those derived from Picric acid and the Picrates;*
- 2d. *Those having Ammonium Nitrate as a principal constituent;*
- 3d. *Those consisting essentially of Nitro-cotton, or other kind of Nitro-Cellulose specially treated with the view of producing a slower burning substance, or of Nitroglycerine and Nitro-cotton.*

**Smokeless Powders derived from Picric Acid and the Picrates.**

During the past twenty years the French government has experimented with picric acid and the picrates with a view of introducing them either as substitutes, as propelling agents in the place of gunpowder, or as charges for shells.

Designolle's, Brugère and Sir Frederick Abel's powders have already been described.

**Poudre B, or Vieille's Powder.** Belonging to the same class presumably is this powder which was adopted some five years ago by the French government for use with the Lebel rifle.

As to its exact composition, nothing definite is known, so jealously have the French military authorities guarded the secret. In a lecture last year, however, Sir F. Abel described few particles that he had seen as follows: "They were in the form of small yellowish brown tablets about .07 to .10 of an inch square, of the thickness of stout note paper, and had evidently been produced by cutting up thin sheets of the material. They appeared to contain picric acid."

It is claimed that a muzzle velocity of 2194 f. s. has been obtained from the Lebel rifle, using this powder, with comparatively low chamber pressure.

Another French powder, known as **BN**, and supposed to be a modification of *Poudre B*, has recently made its appearance. As put up in cartridges, the *BN powder* is cut up into strips of about one-quarter of an inch in thickness, which are laid side by side, and packed in canvas bags for guns of large calibre. For small arms and rapid-fire guns, the strips are broken into grains and packed in metallic cases.

Two samples of this powder have been experimented with by the U. S. Ordnance Department. They were gray or drab in color, and in thin sheets, striated; the sheets were brittle and easily broken along the grooves, and could be readily cut into grains. When granulated by breaking the separated strips, it was found impossible to ignite it, but by reducing the grains still further, partial combustion was obtained. To develop the full force of the powder, however, required a priming of two grains of black powder.

With 45 grains of *BN powder* a mean of six shots (without priming) gave a velocity of 1560 f. s. and a pressure of 35000 pounds.

In these trials some little powder remained unconsumed in the shell after firing, so a second series of six shots were fired with a priming of two grains of black powder, with the following result : velocity 1703 f. s., pressure 52600 pounds.

A second sample of the same powder, but which was, in some respects, superior to that just described, was also tested. With this powder ignition was prompt, no priming being required, and the combustion appeared to be complete.

With 40 grains, the mean of five shots showed a velocity of 1762.6 f. s. and a pressure of 46360 pounds; with 41 grains, the mean of ten shots resulted in a velocity of 1857 f. s. and 53470 pounds pressure; while with 42 grains the mean of fifteen shots gave the remarkable result of 1904.7 f. s. velocity and 57907 pounds pressure.

Notwithstanding the claims as to the excellence of this powder, grave doubts exist as to its stability, and whatever modifications have been made upon the original powder have had but one object in view, to increase its stability under extreme climatic variations.

**Smokeless Powders having Ammonium Nitrate as a principal constituent.** While the sensational reports about *Poudre B* were being circulated in France, the same subject was being investigated in Germany, but along totally different lines. One of the earliest attempts to produce a smokeless powder in Germany resulted in a mixture giving excellent results as regards ballistic properties and uniformity of pressure, but unfortunately these excellent properties were more than counterbalanced by the fatal defect, instability. This powder, known as the *Duttenhofer*, was made at Rothweil, and did not differ materially from the *Amide Powder* already described, ammonium nitrate forming a principal ingredient.

**Chilworth Special Powder.** Belonging to the ammonium nitrate class of smokeless powders is the *Chilworth Special* which, until recently, was used in the Armstrong rapid-fire guns. The ingredients and proportions used are as follows :

Ammonium nitrate,	38 parts.
Potassium nitrate,	42 "
Carbon (prepared as in Brown Powder)	20 "

This powder was used in the ship trials of the *Piemonte's* rapid-fire guns, during which, it is stated, it proved to be not absolutely smokeless, but such smoke as was given off was nearly transparent and soon dissipated. All cartridges made of this powder are put up in hermetically sealed metallic cases containing a cylindrical space through the middle, in which is placed a bag containing one pound of R. L. G. powder. Sir William Armstrong has publicly stated that this powder leaves no residue in the bore to interfere with rapid loading.

On account of its peculiar properties ammonium nitrate has proved very attractive to inventors seeking to discover a smokeless powder.

The products of decomposition of this salt, in addition to the vapor of water, are entirely gaseous, but its *deliquescent* character has so far proved an insurmountable obstacle to its application to service explosives which are subjected to the extremes of climatic changes.

The use of fixed ammunition has rendered it possible to protect these ammonium nitrate powders somewhat by means of sealed cases, but even under these circumstances, they have proved unstable and liable to change and develop varying pressures, when exposed to high temperatures for any length of time. The last stage in the investigation with this substance has resolved itself in experiments looking to the production of a coating for these powders which will render them insensible to atmospheric influences.

**Smokeless Powders consisting essentially of Nitro-cotton, or other kind of Nitro-cellulose.**

So far as smokelessness is concerned, no material can compare with ordinary tri-nitro-cellulose or military gun-cotton. An examination of the chemical changes attending the metamorphosis of gun-cotton and that of gunpowder will serve to explain the absence of smoke in the one case, and the production of smoke in the other. In the case of gun-cotton the products of explosion consist exclusively of gases and vapor of water; while upon the explosion of gunpowder only about 43 per cent. of the products

appear in the gaseous state, 57 per cent. being in the form of a solid residue, which is distributed through the gases and vapors in a finely divided state, thus producing smoke. Although this property of gun-cotton has been known for twenty-five years, the great difficulty experienced in controlling its rate of combustion has prevented its use as a propelling agent. Recent experiments, however, indicate that this difficulty has been in a great measure, if not entirely, overcome, and of the numerous smokeless powders that have been proposed and tested during the past five years, only those derived from the nitro-cellulose class seem to give promise of ultimate success.

**Turpin's Smokeless Powder.** In the specifications of his letters-patent, M. Turpin sets forth the underlying principle of all smokeless powders of the nitro-cellulose class as follows :

"Many attempts have been made to employ gun-cotton for charging fire-arms, but whether loose or compressed (even if coated with paraffin or camphor), its inflammation under pressure is so rapid, owing to the penetration of the flame through the fibres and mass as to often produce a detonation and generally such high pressure as to burst the fire-arm.

"I have found that if the gun-cotton when more or less nitrated be brought to a compact condition such that the rapid ignition of the entire mass is prevented, and that, on the contrary, its combustion proceeds uniformly from the exterior to the center of the grains of the powder, whatever may be their size, the rate of combustion, as well as the initial pressures developed at the moment of combustion, may be easily regulated by varying the size of the grains. In this manner, powders of various kinds may be produced capable of imparting very high velocities and very low trajectories with comparatively low pressure and devoid of shattering properties."

Following this principle, he dissolves gun-cotton, more or less nitrated, in a hermetically closed vessel by means of a suitable solvent. Among the solvents suggested are various nitro-bodies of the aromatic series, aniline, acetone, acetic acid, and ethers; but he seems to prefer a mixture of a low grade of nitro-cotton and ammonia in solution in sulphuric or other ether, or mixtures of ethers, which he terms "composite ethers."

The ingredients and proportions noted as having given satisfactory results are as follows :

Tri-nitro-cellulose,	.	.	.	.	.	250 grammes.
Acetone	.	.	25 to 30 parts	} Composite Ether . 1 litre.		
Sulphuric Ether	.	.	75 to 70 "			
and						
Tri-nitro-cellulose	.	.	.	.	.	150 grammes.
Solution {	Soluble gun-cotton	.	.	.	100	"
	Sulphuric ether	.	.	.	1	litre.

Having reduced the mass to a pasty state, it is next rolled into sheets of the desired uniform thickness by being warmed and passed through metal rollers. After passing through the rollers for the first time, the sheet should be three times the thickness it is to have finally, to allow for shrinking during the drying process which follows, and also for subsequent rolling. The sheet of paste is next placed in a sealed box and heated gently to drive off all traces of the solvent, which is condensed and recovered. The sheet is further pressed to reduce it to the absolute thickness required, and then cut, first into strips, and these strips crosswise, thus forming cubes of various sizes depending upon the gun for which the powder is intended. The smaller the grains the more rapid will be the rate of burning, and the higher will be the initial pressure and initial velocity of the projectile. M. Turpin states that the size of the grain should be proportional to the calibre of the gun, and assumes, as his basis of computation, a powder of a grain of one cubic millimeter for a calibre of ten millimeters.

For artillery it is stated that the powder need not be granulated, but may be used in the form of strips of the same length as the chamber of the gun, and square in section, the sides of square being proportional to the calibre of the gun.

According to the claims of the patentee a weight of charge equal to one-half of that of ordinary gunpowder produces a considerably higher initial velocity than is imparted by the older powder.

**Wetteren Smokeless Powder.** During the year of 1889, it was announced in the Belgian Journals that a very satisfactory smokeless powder had been manufactured at the Royal gunpowder factory at Wetteren, but beyond the scant information contained in

name of "paper powder", no knowledge as to its composition has been vouchsafed. In color it is almost black, is of uneven grain and possesses but little lustre, and the very characteristic odor of pineapple.

Experiments abroad showed that a charge of 45 grains would impart to a bullet weighing 216 grains an initial velocity 1968 f. s. while producing a pressure of only about 7 or 8 tons.

When tested at the National Armory at Springfield, the following results were obtained :

Charge, 28 grains produced a velocity of 1610 f. s. and pressure of 42650 pounds ; charge, 30 grains, 1668 f. s. velocity and 57600 pounds pressure ; Charge, 31 grains, 1755 f. s. velocity and 60035 pounds pressure.

Great stability is claimed for this powder, and it is said not to be at all injurious to the gun.

Unfortunately all efforts to secure samples of this as well as of other smokeless powders recently invented have proved futile, except in such minute quantities as to preclude the possibility of subjecting them to the ordinary service tests for stability, or to even quantitative analysis.

**DuPont Smokeless Powder.** During the past year Messrs. DuPont, of Wilmington, sent to the National Armory for trial samples of a smokeless powder invented by them. In color and odor it closely resembled the Weteren powder, but instead of the small uneven grain, the DuPont powder was granulated, the grains being almost cubical in shape, varying between 0.055 and 0.065 inch on an edge. The grains were hard and smooth, and appeared to have been slightly glazed. This powder was very nearly smokeless, and fouled the gun but slightly, but after allowing the gun to stand forty-eight hours, the bore was found to be rusted.

As compared with the Weteren powder, the following results were noted :

Charge, 28 grains produced a velocity of 1737 f. s. and a pressure of 40900 pounds ; charge, 30 grains, 1867 f. s. velocity and 58380 pounds pressure ; charge, 31 grains, 1900 f. s. velocity and 60030 pounds pressure.

It thus appears that the American powder was considerably superior to the Belgian, as it also proved to be in comparison with



all other powders tested except in the case of one sample of Maxim powder. The velocities recorded were instrumental and taken at the distance of 50 feet from the muzzle.

#### **Maxim's Smokeless Powders.**

The report of the Chief of Ordnance for 1890 contains accounts of somewhat extensive trials of smokeless powders patented by Mr. Hiram S. Maxim, one variety of which proved superior to all other powders tested.

According to the specifications of his English letters-patent, the inventor claims as his object "the production from gun-cotton of an explosive which will be comparatively smokeless, or will, by its combustion, produce much less smoke than gunpowder, and which, when used in a fire-arm, will burn slowly as compared with ordinary gun-cotton. and will exert a high pressure on the projectile.

The process of manufacture differs somewhat from those previously mentioned, and is described as follows:

It (tri-nitro-cellulose) is first reduced to pulp in water in a rag-engine or pulping or other suitable machine, and then thoroughly washed and dried. The dried pulp is then placed in a strong metal cylinder or chamber, and the air is exhausted from the said cylinder or chamber, that is to say, a vacuum or partial vacuum is created therein. The vaporized solvent, consisting of acetone either alone or mixed with ether or alcohol, or with both of these substances, is then allowed to enter, or is forced into the said cylinder or chamber.

The air being entirely removed from the interior of the fibres of the cotton, the vaporized solvent will penetrate to the core of every fibre, and the product will be entirely free from air-bubbles and from empty spaces or interstices such as exist in ordinary gun-cotton.

After the treatment of the gun-cotton with the vaporized solvent as above described, the explosive material thus produced is preferably subjected to very high degree of compression, and is then, if desired, cut or divided into pellets, grains, or other pieces of any suitable dimensions."

Specimens of this powder had the appearance of artificial amber, but possessed less lustre. It had evidently been rolled into very thin sheets, and subsequently cut into small squares, or, in

the case of the roughly granulated specimen, simply broken. Ignited in the open air it burned more slowly than gunpowder, with but little flame, and no perceptible smoke. The specimens submitted by the inventor for trial by the Ordnance Department differed considerably in composition from those described, and in one case, also in form.

**Maxim's Granulated Smokeless Powder.** This form of powder was made by rolling the explosive into very thin sheets and cutting the sheets into squares. The composition of one sample tested was as follows:

Gun-cotton	. . . . .	94 parts.
Nitroglycerine	. . . . .	5 "
Castor oil	. . . . .	1 "

The ordinary service primer used in the Springfield rifle cartridge failed to ignite the charge, and special primers had to be made for the trials.

As a mean of five shots, the charge being 38 grains, a velocity of 1952.4 f. s. was obtained at a distance of 50 feet from the muzzle, and a pressure of 53700 pounds.

A second sample consisting of

Gun-cotton	. . . . .	50 parts.
Nitroglycerine	. . . . .	48 "
Castor oil	. . . . .	2 "

was tested with the following results:

Charge, 28 grains, velocity 1540 f. s., pressure 28800 pounds.

Charge 36 grains, velocity 2044.7 f. s., pressure 58730 pounds.

A third sample, the grains of which were cubical and about 0.054 inch on edge, and of the following composition was also tested:

Gun-cotton	. . . . .	50 parts.
Nitroglycerine	. . . . .	50 "

For corresponding pressures, there was considerable gain in velocities as compared with the samples previously tested.

**Maxim's Cordite.** Several samples of this variety of smokeless powder were submitted for trial.

The composition of these powders is identical with that of the powders just described, the only difference being in the particular form of granulation, so to speak.

Instead of being rolled into sheets and cut up, the explosive material, while in a pasty, or jelly-like state, is forced through holes thus forming cords, which at first are soft and pliable, but which become tough after evaporation of the solvent. These cords (hence the name) may be round or square in section, and are generally cut the necessary length to fit the cartridge cases. The rate of burning depends upon the thickness of the cords.

The cordite tested was in cylindrical pieces about 1.64 inches long and 0.05 inch in diameter. It required about 26 of these pieces to make a 40-grain charge.

The results of the experiments with cordite were practically the same as those already given in the case of the granulated variety just described.

\* A competitive trial between ordinary black gunpowder and the Maxim smokeless powder was held in England with the view of determining the comparative smokelessness of the latter. Thirty rounds were fired from a Maxim automatic machine gun, calibre 0."45, using black powder, after which it was impossible to see the target; while throughout a series of fifty rounds with the new powder the target was clearly discernible. It is said that at a distance of 600 yards it is impossible to fix the position of a firing line from the smoke indications, and at that distance also the report is scarcely audible.

A still greater advantage claimed for this powder is its stability, and that, if thoroughly moistened with water, it regains its efficiency after drying.

**Ballistite.** This smokeless powder is the invention of Mr. Alfred Nobel and has given such satisfactory results that several foreign powers are said to have abandoned their own special powders and made contracts not only for large amounts of this material, but have taken measures looking to its manufacture under their own control.

This is notably the case with Italy, while during the past two years Krupp has used it almost exclusively. As described in the specifications of his letters-patent, one variety is made as follows:

Camphor . . . . .	10 parts
are dissolved in	

Nitroglycerine . . . . .	100 parts
to which solution is added	

Benzole . . . . .	200 parts.
Nitro-cotton (dry and prepared) . . . . .	50 parts

are then carefully steeped in this mixture and the benzole evaporated. The mixing is completed by passing the pasty mass through steam-heated rollers. When the mass is perfectly homogeneous, it is rolled out into sheets and cut up into grains, or molded into any desired shape.

For small arms this powder is prepared in the form of cubical grains, but, for larger guns, in strips of a square cross-section which are cut the length of the cartridge case into which they are to go, and are ignited by means of a *detonating primer*. These strips are of a polished dark brown on the outside, and, when broken, present a section of dark brown color with minute yellow specks. In the open air they burn quickly, with a light hissing noise, and give off a bright yellow flame. In Germany this powder is officially known as C | 89, and is supposed to have been one of the powders used in the Army manoeuvres of 1889, which was described by eye-witnesses as practically smokeless, only a thin brown vapor being discernible from the flanks, and scarcely anything at all from the front, but showing a vivid flash.

When tried in an 8.27-inch, 35 calibre high power gun, a charge of 51.7 pounds imparted to a 238-pound projectile a muzzle velocity of 2329 f. s. with a chamber pressure of but 14.6 tons per square inch.

Extensive trials from rapid-fire guns were carried on at Krupp's works last summer with this powder, during which, some of it was soaked in water of 17° C for thirty minutes, then taken out and dried, and two charges of it fired from a 7.5-cm. 28-calibre gun with the following results:

WEIGHT OF CHARGE	WEIGHT OF PROJECTILE	VELOCITY AT 131 FT. FROM MUZZLE	CHAMBER PRESSURE
lbs.	lbs.	f. s.	tons per sq. in.
1	15	1424	10.4
1	15	1424	10.5

Experiments with this powder in high power guns conducted by the Italian Government gave excellent results.

The Italian Minister of War has stated that extensive experiments with *ballistite* had proved that its chemical stability remains unchanged during considerable increase of temperature, and that it can be transported without danger ; that shots may be fired into cases of cartridges loaded with ballistite without producing explosion, and that a loaded cartridge had been exploded in a full packet of charged cartridges without detonating the others.

Subsequent to these statements, however, we have reports of an explosion of a factory at Avigliano containing a large quantity of this powder, which resulted in the deaths of several workmen, but no details of the accident have been published.

The first issues of the new English magazine rifle were sighted for a muzzle velocity of 2200 f. s., using one variety of Nobel's powder.

A sample of this powder, consisting of a single piece  $3'' \times 2'' \times 1''$ , was submitted for trial to the Ordnance Board at the Springfield Armory.

Compared with the Wetteren and Maxim powders already described, it was found that for equal pressures, the Nobel powder gave greater velocities than the Wetteren, while the results did not differ materially from those obtained with the Maxim explosive. It was noted, however, that the Nobel powder required a priming of black powder, while at the same time it gave an increase in both velocity and pressure.

### **Hengst Smokeless Powder.**

English letters-patent No. 13656 of 1889 relate to a smokeless powder invented by Mr Charles F. Hengst, which differs materi-

ally from any of those already mentioned. It consists essentially of nitro-straw thoroughly purified, compressed and granulated. One variety of the powder is made as follows :

An acid mixture consisting of

Sulphuric acid (Sp. Gr. 1.850) . . . . . 3 parts,

Nitric acid (Sp. Gr. 1.486) . . . . . 1 "

is prepared and allowed to cool. Into this mixture is introduced "as much pulp—preferably of oat straw—as the bath (mixture) will take up to undergo a process of maceration."

After standing for about from 15 to 20 hours, the acid is strained off and the pulp washed in water until no traces of acid remain. The mass is next steeped in a solution of hyposulphite of soda, or other suitable alkaline solution, and then slowly dried. When dry it is compressed and granulated.

Tested with ordinary gunpowder, a smaller charge imparted increased velocities ; when fired it gave but little smoke, the character of which was that of vapor which rapidly condensed and almost immediately disappeared ; it emitted a faint bluish flame upon explosion, and left but little residue in the piece.

From the description of this powder it is evident that it is simply a *nitro-straw*, and while it may possess some of the good qualities of military gun-cotton, it is safe to assert that, as an explosive to be used as a propelling agent in fire-arms, it possesses in an equal degree the disadvantage which has in past years proscribed the use of that explosive for similar purposes.

#### **Munroe's Smokeless Powder.**

Highly satisfactory results have just been obtained by the Naval Bureau of Ordnance with a brand of its own smokeless powder. The trial took place at the Indian Head Proving Grounds, in 3-pounder and 6-pounder rapid fire guns. Eleven rounds were fired from the 6-pounder and eight from the 3-pounder. The final results with the 6-pounder were as follows :—With a charge of 400 grammes 1,960 feet velocity per second was obtained, the pressure being 16 tons ; with a charge of 392 grammes 1,929 feet velocity was obtained, with the remarkably low pressure of 14 tons. With over double the quantity of the ordinary black powder the highest velocity obtained with this gun is only 1,800 feet per second, with a pressure of 15½ tons.

With the three pounder still better results were recorded, a velocity of 2,250 feet per second being secured with the small charge of 310 grammes, the pressure being less than fifteen tons. With the service charge of ordinary black powder 760 grammes and a pressure of fifteen tons, the highest velocity recorded for this piece is 2,000 feet.

A specially gratifying feature of the results was the extreme regularity, uniformity and correspondence of velocities with pressures which was apparent throughout the tests. The results with the 3-pounder are somewhat more favorable than those which have been obtained abroad, especially in regard to low pressure. With the French smokeless powder a velocity of 2,362 feet was obtained with a gun of the same size, but the pressure was one ton higher. The results with the 6-pounder compare favorably with those furnished by the foreign powders.

This new naval smokeless powder is the invention of Professor Charles E. Munroe, the government chemist at the Torpedo Station.

This powder is quite as free from smoke as any of the so-called smokeless powders. It throws off a slight haze, which is promptly dissipated, only appearing at discharge. It is necessary, however, to use a small priming charge of black powder, as is done with the new foreign brands, the smokeless grains being difficult of ignition. Certain features of the manufacture are kept secret in the interest of the government.

**Conclusions.** The essential requisites of a perfect smokeless powder are : approximate smokelessness ; completeness of combustion ; high and regular velocities with moderate and uniform pressures ; stability under varying conditions of climate, temperature and long storage ; and freedom from noxious and irrespirable gases when exploded. In no powder yet produced has absolute smokelessness been obtained. The term is relative only, and signifies that the amount of smoke given off on firing is so insignificant as not to obscure either the firer or the object aimed at, and so quickly dissipated as to admit of continuous firing under those conditions. In addition to the essential properties to

be possessed by these new powders, another and very important object has been sought after, namely, impossibility of *detonation* by chemical or mechanical means.

From the records of trials up to the present time, the new powders appear to possess better ballistic properties than the ordinary powders, much smaller charges being required to produce the same velocities and chamber pressures. In its normal state, the smokeless powder acts gradually and continuously, giving lower chamber pressures, but the pressures appear to act all along the walls of the gun. A necessary modification in gun construction would therefore follow the permanent adoption of these powders, in which the size of the powder chamber would be reduced, while the walls would have to be strengthened throughout the chase.

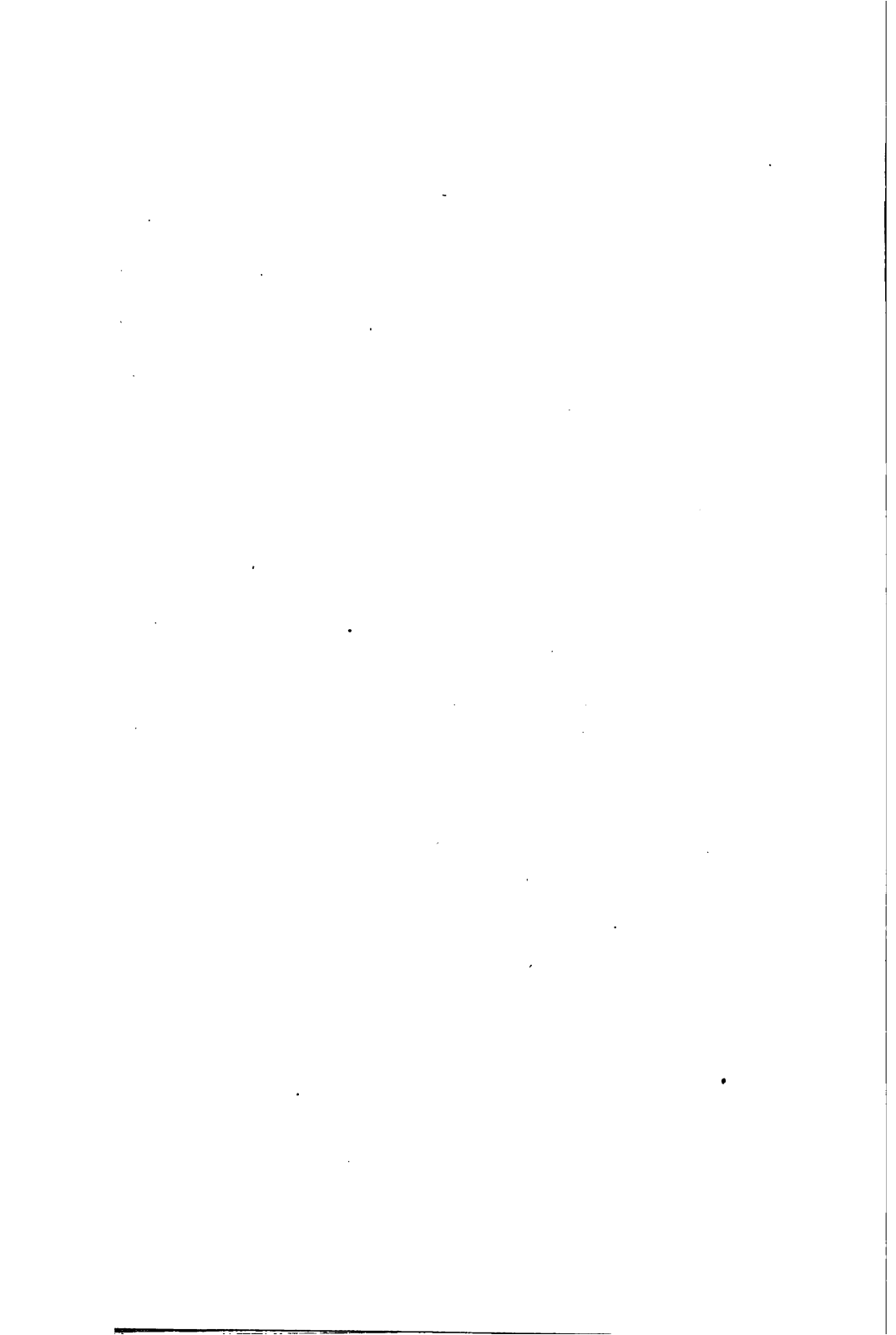
The absence of fouling residue, which, with ordinary powders, acts as a lubricant, would also necessitate the use of lubricants.

There can be no doubt but that the smokeless powder is a permanent innovation, although it will probably be some years before such a powder will be produced which may be said to possess all the necessary qualities required in a service explosive.

**Tests for Smokeless Powders.** The several tests already enumerated and described for the determination of the condition of the high explosives of the nitroglycerine and gun-cotton classes are equally applicable to these derivatives. The time allowed for the stability test will vary slightly, but the exercise of a little judgment will enable the operator to decide upon the limit for any particular powder.

For a final determination as to the ingredients and the proportions which enter into such a compound, the outline of quantitative analysis for nitroglycerine preparations already given is applicable.





## LECTURE XVIII.

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### EXPLOSIVES OF THE SPRENGEL CLASS.

In 1873, Dr. Hermann Sprengel proposed a new class of explosives which have recently attained great prominence on account of the success that has attended their manufacture and use.

The essential principle of all explosives of the Sprengel class is *the admixture of an oxidizing with a combustible agent at the time of, or just before being required for use, the constituents of the mixture being themselves separately non-explosive.*

In 1871, Mr Silas R. Divine filed a caveat in the confidential archives of the U. S. Patent Office to protect his claim to the invention of Rack-a-Rock, which is a typical explosive of this class, but he published no patent until 1880.

To Dr Sprengel, therefore, it appears, belongs the credit of the first publication of the general underlying principle of this important class of explosives.

In order to realize and ensure a speedy and intimate mixing of the ingredients, Dr Sprengel's original plan was to use substances, one or both of which should be in a liquid state.

Among the oxidizing agents proposed were the various nitrates and chlorates, which are solid, and nitric acid, nitrogen tetroxide, etc., which are liquid; while among the combustible substances were enumerated the nitrosubstitution products, carbon bisulphide, petroleum, etc. On account of the existing laws of England, these explosives cannot be licensed in that country, but their use in this country is quite general. All explosives of this class are powerful, and the majority of them possess a remarkable degree of stability, requiring very strong detonators to provoke explosion and develop their full force. When nitric acid is one of the ingredients (as in Hellhoffite, Oxonite, etc.), the greatest care

is necessary to protect the detonator from the action of the acid. Should such contact occur, premature explosion would surely result, due to the rapid corrosion of the copper, and the consequent action of the acid on the detonating mixture. With all such explosives therefore, *it is necessary to thoroughly coat the detonator with paraffin before introducing it into the explosive.*

**Rack-a-Rock.** This is one of the best known of these mixtures, and consists of potassium chlorate and mono-nitro-benzene (Sp. Gr. 1.33). According to general Abbot, the best results are obtained when these ingredients are mixed in the following proportions :

Potassium chlorate . . . . .	79 parts.
Mono-nitro-benzene . . . . .	21 “

The ingredients are transported and stored separately until required for use. Two general methods of mixing are pursued, one by dipping the chlorate cartridges in a pail of the liquid, the other by placing the cartridges in a pan arranged with cells to receive them, and pouring the liquid over them.

In the first case, the cartridges are placed in tiers in a wire basket made for the purpose, and the basket lowered into the pail containing the liquid, subjecting the cartridges to immersion from 3 to 6 seconds, depending upon their size. The basket is then withdrawn, the cartridges allowed to drain for a few moments, and at the end of ten minutes, they are ready for use.

The mixing is accomplished more nearly according to the required proportions by means of the saturation process than by dipping as just described.

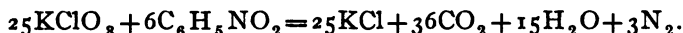
Each size of cartridge has its corresponding cell and cup, into which it is placed ; and on each cartridge is poured exactly one full cup of the liquid. As soon as the liquid is entirely absorbed, the cartridge is removed, and after the lapse of ten minutes as before it is ready for use.

Rack-a-Rock is a compact solid having a specific gravity of 1.7. According to General Abbot, “it decrepitates with difficulty when hammered on an anvil, but hardly ignites on wood”. A fuse containing 24 grains of fulminating mercury fails to explode a cartridge unconfined or loosely confined. A cartridge struck by a bullet from a Springfield rifle flashes but does not detonate. Or-

dinary friction seems to have little tendency to cause explosion. These facts show it to be quite safe to handle, even when ready for use, and it has given excellent results in rock blasting under General Newton at Flood Rock, 240399 pounds being used on that occasion.

When tested within fifteen minutes after mixing, samples of this explosive have been found quite sensitive to friction between metal surfaces, and even when gently rubbed in a porcelain mortar; while its sensitiveness to percussion has been found to be equal to that of dynamite No. 1.

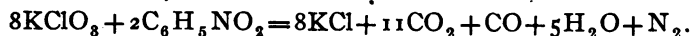
It is very generally believed that the fullest effect to be derived from an explosive demands perfect explosion, which in the case of rack-a-rock would require that all the carbon present should be oxidized to carbonic acid, the hydrogen to water, and the nitrogen set free. Under this supposition, therefore, the following equation would represent the explosion of rack-a-rock:



Whence we see that theoretically, the proportions of the ingredients should be

Potassium Chlorate, . . . . .	89.9 parts.
Mono-nitro-benzene . . . . .	19.1 "

Accepting, however, the proportions given by General Abbot, the equation to be assumed to represent the explosion of rack-a-rock, when the maximum effect is developed, is



Examining this equation, we see that instead of all of the carbon being oxidized to carbonic acid, a small percentage appears in the form of carbonic oxide. And what appears to be true in the case of this explosive has been found to obtain in many others.

**Hellhoffite.** About 1880, Hellhoff, of Berlin, patented a process of making explosives from crude coal-tar oils by direct nitration with strong nitric acid.

The nitro-products thus obtained were thoroughly washed and dried, and then mixed with oxidizing substances; the resulting explosive, he called *hellhoffite*.

Experience gained by long continued manufacture with the aid of steam proved that the separate fractions of the crude tar oils, even those of the highest boiling point, were capable of nitration, and gave satisfactory yield of nitro-derivatives.

Experiments undertaken to see whether crude tar itself could be treated directly with *strong* nitric acid quickly demonstrated that the operation was extremely dangerous, and that its employment on a large scale would be attended with great difficulties.

Therefore the degree of nitration of crude tar was limited to the use of nitric acid of a specific gravity not exceeding 1.45. When liquid tar is gradually stirred into nitric acid (of Sp. Gr. 1.33 to 1.45), the surface of the acid becomes covered with it; by continuing to stir the mixture, the layer of tar contracts and settles slowly to the bottom of the acid; and in about ten minutes the mass at the bottom puffs up, and gradually changes from a liquid to a solid or pasty state. Finally this mass rises from the bottom and spreads itself evenly over the surface.

During the process, tar is added until the acid is entirely used up, which becomes apparent by the new charge of tar no longer contracting and settling.

The amount of heat attending the reaction does not necessitate cooling.

The product thus obtained is well washed with excess of water, and all remaining water is squeezed out of its pores, after which it is mixed with oxidizing substances.

When nitric acid is used, it was found that one part by weight of the nitro-derivative dissolved slowly and with the evolution of but little heat in three parts by weight of nitric acid, Sp. Gr. 1.52, producing a very powerful explosive.

On account of the varying composition of the tar, it is impossible to give the exact proportions in all cases of the oxidizing substances which must be added, but by experiments it has been found that the following limits obtain practically:

Nitro-derivative	1 part
Nitric or Chloric Acid (conc.)	2 to 5 "
or	
Nitro-derivative	1 part
Oxidizing Salts	4 to 6 "

The great advantages offered by this process are cheapness of material to be treated and of the lighter acid used, and the quiet and regular manner in which the operation takes place, this latter feature permitting the use of simple and inexpensive apparatus.

The results obtained from coal-tar led to experiments upon paraffines, mineral oil, pitch, and even upon the original substances, coal and peat.

In the case of paraffin and mineral oil, the weaker acid proved ineffectual, and a mixture of equal weights of the strongest nitric and sulphuric acids, was employed. The nitro-compounds precipitated from the mineral oils were of a light brown or yellow color, of the appearance of rancid fat, and were difficultly soluble in the strongest nitric acid.

Experiments with pitch and coal demonstrated the fact that they presented no advantages which would compensate for the increase in cost of manufacture, but in the case of *peat*, the results were more encouraging.

In the earlier experiments, a firm, solid substance, called "bog peat" (*Moortorf*), from Duneburg, was subjected to the action of equal parts by weight of the strongest nitric and sulphuric acids for several hours. The substance changed color from dark brown to dark red. Ignited in the air, it burned with a lively flame and strong aromatic odor. When soaked in a solution of potassium chlorate and dried, it formed a powerful explosive. If the same peat was well pounded before the nitration, so that the humus substance was separated from the vegetable fibre, and a larger surface was exposed to the powerful action of the acids, the earthy humus constituents were converted into a dark-brown sticky liquid, having the external characteristics of the nitro-substance obtained by nitrating the heaviest tar oils. Its action when mixed with oxygenated bodies is also similar to the latter.

The other nitro-substance, formed from the finely divided fibres left in the dry distillation that attends the formation of peat, yielded an explosive without any admixture of an oxidizing salt. In the open air it burnt very rapidly, leaving a slight carbonaceous residue.

Peat containing animal admixtures acted similarly to that just described.

With peat that appeared to be of later formation, the action of the concentrated acids was more marked and violent. There was a violent evolution of the oxides of nitrogen, and, in spite of the most careful cooling, the heat became so great that there was danger of reaching the ignition point of the nitro-derivative, and the operation had to be interrupted.

The same peat was then treated with ordinary commercial nitric acid, Sp. Gr. 1.35, and the action was almost imperceptible. Concentrated acid was then added gradually, until the resulting acid had attained a specific gravity of 1.45, at which point the action began to be quite violent, and no more of the concentrated acid was added.

After the reaction had proceeded for several hours with careful cooling, the product was washed and dried.

This nitro-product was an explosive without the admixture of an oxidizing body, but not so strong as that made from bog peat with the stronger acids.

Other derivatives made from crude tar oils, when repeatedly nitrated, also form explosives alone ; but they are always weaker than when mixed with oxygenated bodies.

The chief characteristics of the newly prepared nitro-substances are as follows :

Their specific gravity is very nearly that of water ; they all possess a powerful aromatic odor, resembling the fruit ethers, which is particularly noticeable when they are burning ; all solutions of these substances have a strong refractive power. The majority of them are soluble in concentrated nitric acid as well as in alcohol ; they are all insoluble in water. In the open air they all burn with a bright but smoky flame. They are so unstable that they can be exploded alone, or, mixed with oxidizing substances, by simple ignition.

In 1885, while experimenting to find an economical method for breaking up old iron chills, Gruson discovered a new ingredient, which seemed particularly adapted for use in this class of explosives, and, together with Hellhoff, he proceeded to patent a new variety of *hellhoffite*. For some time the nature of this new ingredient was preserved in great secrecy, but gradually the mystery

was cleared away, and to-day it is generally known that Gruson's new explosive, which was reported to the War Department in 1886 by Captain William H. Bixby, consists of (approximately):

Meta-di-nitro-benzene . . . . .	47 parts.
Nitric acid (Sp. Gr. 1.50 . . . . .)	53 "

To make this explosive, the di-nitro-benzene is finely pulverized and then gradually added to the acid, until a thoroughly saturated solution is obtained. Thus prepared *hellhoffite* is a very dark red or brown liquid; but it does not appear to be a new product, but merely a solution, and, if by any chance, the mixture is not required for immediate use, by adding water gradually to the acid, it may be diluted to such an extent that the di-nitro-benzene will be no longer held in solution, and will recrystallize. By straining the mixture, the crystals can be separated and dried, and are then ready to be used again. Of course the diluted acid cannot again be used for making the explosive. To develop the full force of this explosive requires the use of a detonator twice as powerful as that used to explode ordinary dynamite.

Extensive experiments were carried out to prove the superiority of *hellhoffite* over all other existing explosives both for industrial purposes and for military use wherever a perfectly safe but violent explosive was required. Briefly stated, the special advantages of this explosive are

1. When detonated by the fulminate of mercury, it is more powerful than nitroglycerine. Experiments in this laboratory show the relative intensities of the two explosives to be as 106.17: 100.
2. It may be stored and transported with perfect safety as regards concussion, since it cannot be exploded by a blow, shock, or an open flame.

On the other hand, however, it possesses certain disadvantages.

1. It is a liquid.
2. The acid contained in it is so volatile that it can be stored only in perfectly closed vessels.
3. It is rendered completely inexplusive by being mixed with water, and therefore cannot be employed for submarine work.



4. On account of the action of the acid on the copper cases of the detonators, the latter require particular treatment and inspection before use.

The results of the experiments with this explosive conducted by the German Government have not been made known.

**Oxonite.** Like hellhoffite, which it very closely resembles in appearance, this explosive is a simple solution, and is made by dissolving picric acid in concentrated nitric acid.

The action is perfectly quiet and is attended with a slight fall of temperature of the solution.

In experiments in this laboratory, it was found that the proportions required to produce a perfectly saturated solution were as follows:

Picric acid . . . . .	54 parts.
Nitric acid (Sp. Gr. 1.50) . . . . .	46 "

These proportions, however, are subject to slight changes, depending upon the strength of the nitric acid, and also upon the condition of the other ingredient, whether merely pulverized before being added, or *fused* and pulverized. This last condition was also found to materially affect the strength of the resulting explosive. For instance, assuming the standard nitroglycerine to have a value of 100, the relative intensities of the oxonite made with picric acid *not fused* and *fused* were as 64.24 : 69.51.

Oxonite is much less powerful than hellhoffite, and requires a very powerful detonator to develop its full force, it is unaffected by blows, or shock, and is entirely insensitive to friction.

It is generally conceded that this explosive is identical with the "A-explosive" which was surrounded with such profound mystery until the occurrence of serious accidents during its trial as a bursting charge for shells proved it unfit for service. Other accidents, notably one in 1884, have caused oxonite to be regarded with suspicion; but in the case of every accident, the cause can be traced to the disregard of the precaution against allowing the nitric acid to gain access to the contents of the detonator. When prepared commercially, the picric acid, sometimes with the addition of a nitrate, is packed in a muslin bag, which also contains the nitric acid in a hermetically sealed glass tube. This tube is broken by a blow before the cartridge is required for use.

**Panclastite.** This substance is made by mixing liquid nitrogen tetroxide ( $N_2O_4$ ) with combustible substances such as the hydrocarbons; vegetable, animal and mineral oils; fats and their derivatives, but preferably with carbon disulphide. The inventor, Mr. Eugene Turpin, proposes that the two ingredients should be kept apart until required for use, when they may be mixed in varying proportions, depending upon the particular work to be accomplished. The proportions which yield the most sensitive mixture are approximately

Nitrogen tetroxide	. . . . .	3 volumes.
Carbon disulphide	. . . . .	2 "

The nitrogen tetroxide may be prepared

1. By heating lead nitrate ;  

$$2Pb(NO_3)_2 \text{ heat } = 2PbO + 2N_2O_4 + O_2$$
2. By acting on tin with nitric acid ;  

$$5Sn + 20HNO_3 = H_{10}Sn_5O_{15} + 5H_2O + 10N_2O_4$$
3. By acting on nitrosyl chloride with silver nitrate ;  

$$NOCl + AgNO_3 = AgCl + N_2O_4$$
4. By the union of oxygen with nitrogen trioxide ;  

$$2N_2O_3 + O_2 = 2N_2O_4$$

When nitrogen tetroxide is made by any of these processes and passed through a freezing mixture, it condenses into transparent crystals, which melt at  $-9^\circ$ , and which when once melted do not resolidify until cooled to  $-30^\circ$ . Above  $-9^\circ$  it forms a mobile liquid, having a specific gravity of 1.451, which boils at  $22^\circ$ .

The vapors from this gas are of reddish color; possess a pungent, suffocating odor and an acid taste; they stain the skin bright yellow, and are irrespirable.

In making the explosive, the temperature falls about  $20^\circ$ .

*Panclastite* ignited in the open air burns with an exceedingly brilliant flame; confined in a vessel and ignited, it burns until the pressure of the gases produce an explosion. Exploded however by a fulminate, whether in the open air or confined, the explosion is complete and powerful, whereas in the former case only a portion of the substance explodes, the remainder burning away quiet-

ly. The advantages claimed for this explosive are greater power than dynamite, perfect safety of the separate constituents in transport and storage, and insensitiveness of the mixture to blows.

**Roburite.** This explosive is the invention of Dr Carl Roth, a German chemist, and, according to the license authorizing its manufacture in Great Britain, it consists of

- “(a) Nitrate of ammonium with or without an admixture of nitrate of sodium and neutral sulphate of ammonium, or either of them, provided that the amount of nitrate of sodium shall in no case exceed 50 per cent. of the total amount of nitrates present, and
- (b) Thoroughly purified chlorinated di-nitro-benzole with or without the addition of thoroughly purified chloro-nitro-naphthalene and chloro-nitro-benzole; provided (1) that such chlorinated di-nitro-benzole shall not contain more than four (4) parts by weight of chlorine to every one hundred (100) parts by weight of chlorinated di-nitro-benzole; and (2) that the proportions of chloro-nitro-naphthalene and chloro-nitro-benzole shall not amount to more than 2 per cent. and 5 per cent. respectively of the finished explosive.”

The inventor of roburite claims for it the following advantages:

1. The ingredients are perfectly harmless and inert separately, so that they can be stored and transported without any restriction whatever.
2. That no precautions are necessary in mixing, and, even when mixed, the explosive is perfectly insensitive to friction, percussion and the application of an open flame or a heated body; it can be exploded only by means of a detonator containing fulminate of mercury.
3. That when detonated, roburite produces neither spark nor flame.
4. That the amount of noxious gases produced by its explosion is infinitesimal.
5. That roburite is not subject to deterioration through climatic variations of temperature. It should be kept dry, but if it becomes damp, its strength can be safely restored by drying.

In 1887 this explosive was subjected to severe tests by the English Government under the superintendence of Major Sale, R. E., the object of the trials being to compare roburite with gun-cotton, dynamite and blasting gelatine.

Major Sale concluded his report as follows :

“In summing up the results of the foregoing experiments we must bear in mind the great difficulty—we had almost said the impossibility—of obtaining any absolute standard of comparison of the relative strengths of two or more explosives. Each will seem to prove itself superior for certain purposes. Judged, however, by any standard of comparison, it appears that the new explosive has acquitted itself very well, and, especially when we consider its absolute safety, must have a great future before it. Roburite has shown itself to be in some respects more powerful than dynamite, to which it is likely to prove a serious rival in the industrial field, although the latter has the proverbial advantage of strong possession of the ground. An important element in the struggle for ascendancy will be the price at which roburite can be supplied as compared with dynamite, and this will be, we understand, strongly in favor of the new substance.

“But although quite outside the scope of Tuesday’s experiments, the great power and safety of roburite seem eminently to fit it for use as a bursting charge for shells, into which its granular form would allow it to be conveniently loaded.

Much stronger than any picric powder, and doubtless better able to withstand the concussion of the discharge of the gun, an extended series of trials would be necessary to determine the best mode of so employing it.”

**Romite.** This substance consists of a mixture of ammonium nitrate, naphthalene or nitro-naphthalene, and potassium chlorate. It was invented by Mr Sjöberg, a Swedish Engineer, and has been tested in shells by the Swedish Artillery, with generally satisfactory results.

An investigation, however, into the cause of some thirteen explosions which occurred at various places in Stockholm during a heated period of 1888, disclosed the fact that, in eleven of the thirteen places, *romite* had been stored, and the accidents were *all*

attributed to the "spontaneous ignition" of this explosive. Since these accidents, little or no attention has been given to the further adoption of this explosive.

The practical advantages of the Sprengel Explosives as a class, especially for military purposes, are apparent. Safe in storage and transportation, the only source of danger seems to lie in proper manipulation when the explosive is required for use, and this, under the supervision of intelligent officers, can be reduced to a minimum. The perfect control over the power to be developed by the explosive lies within the hands of the manipulator, and by varying the proportions of the ingredients, an explosive more violent than dynamite, or less powerful than blasting powder can be prepared at a moment's notice. The precautions required in preparing the detonators for use with those explosives of this class containing a large percentage of concentrated nitric acid have already been alluded to.

## LECTURE XIX.

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### FULMINATES, AMIDES, AND SIMILAR COMPOUNDS.

#### **Chemical composition of the Fulminates.**

The fulminates are now regarded as metallic salts of a hypothetical fulminic acid, or fulminate of hydrogen, the formula for which is  $\text{H}_2\text{C}_2\text{N}_2\text{O}_2$ .

This acid which has an intermediate composition between cyanic acid  $\text{HCNO}$ , and cyanuric acid  $\text{H}_3\text{C}_3\text{N}_3\text{O}_3$ , has never been obtained in a separate form, but the fact of the existence of double fulminates and acid fulminates, and the intimate relation existing between the fulminates and the cyanogen compounds, are accepted as evidence of the existence of such a compound.

**Mercury Fulminate.** In the Philosophical Transactions for the year 1800, Howard stated that when mercury was heated with nitric acid and alcohol an explosive compound was formed. This substance, which was subsequently known as Howard's fulminating mercury, appeared as a whitish salt which crystallized in acicular needles possessing a saline taste and which, when dried, exploded with extreme violence when struck upon metal, or when a drop of sulphuric acid was poured upon it. In the earlier attempts to substitute mercury fulminate for gunpowder as a propelling agent, it was found to impart but low velocities to the bullets, while in nearly every case, it burst the gun. In other words the extreme violence of its action locally, and the great difficulty met with in controlling this action led to its disuse until the introduction of percussion caps and primers.

Quite a number of methods have been proposed and used for the manufacture of mercury fulminate, but the following has given the most satisfactory results when small quantities are required for experimental purposes.

Introduce into a flask, of about 300 c. c. capacity,

Mercury . . . . . 10 parts.

Nitric acid (Sp. Gr. 1.40) . . . . . 120 "

and heat gently until all the mercury is dissolved, and allow the solution to cool, shaking the flask from time to time to secure homogeneity, and then pour it into a flask (2000 c. c. capacity) containing

Alcohol (95 per cent.) . . . . . 110 parts.

The latter flask should be placed in the open air or under a hood, so that the fumes evolved during the reaction may be rapidly dissipated, and also at a distance from any naked light, or other source of ignition.

As soon as the reaction is finished, fill the flask half full of filtered water and allow the greyish powder to settle. The supernatant liquid is then poured off, and the washing is repeated as long as the decanted wash-water shows any traces of acid reaction. At an atmospheric temperature of 60° F; or above, no heating is required to start the reaction, but should the temperature fall below 60° (shown by the reaction ceasing), the flask should be placed in a vessel containing warm water until effervescence recommences. During the washing *extreme care* must be taken that no fulminate accumulates on dishes, beakers, or floors, or is carried into drains, for serious accidents have resulted from minute quantities having been spilled and having remained unnoticed until dry when an explosion resulted. Should any be spilled, it should be destroyed at once by means of a solution of an alkaline sulphide.

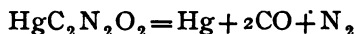
The reactions attending the formations of mercury fulminate by this process may be represented as follows:

1.  $3\text{HNO}_3 + \text{Hg} = \text{Hg}(\text{NO}_3)_2 + \text{HNO}_2 + \text{H}_2\text{O}$
2.  $\text{C}_2\text{H}_5\cdot\text{OH} + \text{HNO}_2 = \text{C}_2\text{H}_5\cdot\text{NO}_2 + \text{H}_2\text{O}$
3.  $\text{C}_2\text{H}_5\cdot\text{NO}_2 + \text{HNO}_2 = \text{H}_2\text{C}_2\text{N}_2\text{O}_2 + 2\text{H}_2\text{O}$
4.  $\text{H}_2\text{C}_2\text{N}_2\text{O}_2 + \text{Hg}(\text{NO}_3)_2 = \text{HgC}_2\text{N}_2\text{O}_2 + 2\text{HNO}_3$

Made in this manner, mercury fulminate is in the form of fine crystals which appear under the microscope to consist of orthorhombic crystals which are twinned along the vertical axis. It is found by experience that the finer crystals are better adapted for use in detonators than the coarser ones.

Dry mercury fulminate explodes violently when struck or compressed, or rubbed between hard surfaces ; or when touched with strong sulphuric acid, or an incandescent wire, or ignited body. Saturated with 30 per cent. of water, it is inexplusive unless primed with a small quantity of dry fulminate, in which case it may be readily and completely detonated. Although Abel has succeeded in causing mercury fulminate to undergo gradual combustion, yet, in practice, the dry fulminate invariably detonates, not only when unconfined, but even in vacuo.

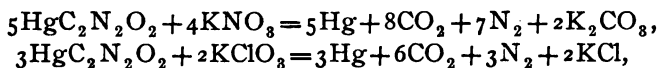
The density of mercury fulminate is 4.42. Its heat of formation (for one equivalent 284 grammes) is  $-62900$  calories. Its heat of combustion, in an inert atmosphere is  $+116000$  cal. for constant volume, and  $+114500$  for constant pressure. This quantity of heat would be sufficient to raise the temperature  $4200^{\circ}$  C. Its heat of combustion in air is  $+250900$  cal. the reaction attending its decomposition may be represented as follows:



According to this equation one gramme of the fulminate should yield 235.8 c. c. of gas. Berthelot and Vieille have verified this several times, obtaining 234.2 c. c. Therefore one equivalent (284 grammes) would furnish 66.7 litres of gas at  $0^{\circ}$  C and 76 cm.

From the above equation it is seen that mercury fulminate, when detonated, does not give rise to the formation of any substance capable of undergoing a notable dissociation under the conditions of the experiment, consequently no gradual recombination can take place during the cooling which would retard the expansion of the gas and diminish the violence of the initial blow. This explains the brusqueness of the explosion, which would be all the more violent but for the condensation of the mercury vapor.

When mercury fulminate is mixed with potassium nitrate or chlorate and exploded, the following reactions may occur :



the first of which evolves  $+227400$  cal., and the second  $+258200$  cal., the heat evolved here being double that from the pure fulminate, but the initial blow is tempered here by the phenomena



of dissociation, due to the carbon dioxide, which renders these explosive mixtures less brusque in their effects. The temperature is also reduced at the outset by the distribution of the heat among the more considerable mass of products.

The superiority of the power of mercury fulminate is manifested best when in contact with a body, and it is due to three causes :

1. The nearly instantaneous decomposition of the body by simple inflammation ;
2. The almost total absence of dissociation products ; and
3. The great density of the explosive.

By reason of these conditions, the definite products of the reaction appear to form all at once, before the matter has time to take a volume notably superior to that of the primitive solid. If, then, the fulminate detonates in a receptacle, in contact with the sides of the same, it develops on it at the start, an instantaneous pressure which bears no definite relation to the mean pressure controlled by the capacity of the receptacle. The superiority of the effects produced by the explosive shock of the fulminate over that of other explosives is explained by this circumstance joined with the absence of dissociation.

It is known that the fulminate of mercury is eminently fitted for determining the nearly instantaneous propagation of detonation, which is absolutely necessary in order to develop the entire power of dynamite, gun-cotton, etc. Berthelot's theory in explanation of these characteristic effects will be referred to later.

**Percussion Caps.** Mercury fulminate is largely used for filling percussion caps. For this purpose 100 parts of the dry fulminate are rubbed to powder with 30 parts of water, 50 to 62.5 parts of saltpetre and 29 parts of sulphur, the mixing or rubbing being done by means of a wooden pestle on a marble slab.

This mixture is dried until it can be granulated, after which it is introduced into the copper caps by machinery, and immediately covered with a layer of varnish or tin-foil to protect it from moisture. The caps are subsequently dried by a gentle heat and packed in boxes.

*Blasting caps or detonators* consist of copper caps about  $1\frac{1}{8}$  inches in length and  $\frac{1}{4}$  inch in diameter, which contain different quantities of the fulminate mixture, according to the strength required.

They are of two general forms, one to be fired by electricity, the other for use with ordinary time fuses.

In the *electric fuse* the mouth of the cap is closed with a wooden plug, sealed with sulphur and glass, which carries the legs connecting the bridge with the leading wires. The U. S. Navy detonator is an excellent example of this class, although in size and strength it differs somewhat from other electric fuses made for commercial purposes. It consists of a copper case made in two parts. The lower part is a No. 38 metallic cartridge case and is  $1\frac{1}{8}$  inches long and  $\frac{11}{16}$  inches in diameter. The upper part is a copper tube, open at both ends,  $\frac{5}{8}$  inches long and  $\frac{11}{16}$  inches in diameter. A  $\frac{8}{16}$ -inch thread is cut on each of these parts so that the upper part screws nicely on the lower. The lower part is filled with fulminate of mercury (35 grains) up to the lowest thread of the screw. The upper part is fitted with a plug of sulphur and glass, through which the detonator legs pass to connect the bridge with the wires leading to the battery. When the fulminate is dry the spaces in the lower case and the caps are filled with pulverulent dry gun-cotton, and then the parts are screwed together.

When made for use with the Bickford or similar *time fuses* which are to be lighted by means of a match, the mouth of the copper case is left open so that a piece of the fuse may be inserted in the cap, which is afterwards tightly *crimped* around the fuse.

There are several grades of detonators which apply to both classes, and are known as single, double, triple, quadruple and quintuple force caps. The single force caps contain three grains of the fulminate, and the others increase regularly by three grains. The fulminate used in ordinary blasting caps consists of 75 parts of mercury fulminate and 25 parts of potassium chlorate, to which is added sometimes a little gum dissolved in alcohol, to make the mass more coherent.

The addition of chlorate cheapens the cost and adds to the efficacy of the caps when used with low grade powders containing a gunpowder dope.

Practically blasting caps may be tested by fitting a cap in a cork so that the base of the cap is just flush with the bottom of the cork, and firing it on a sheet of Swedish iron supported at its four corners. A good cap should blow a clean hole through No. 14, A. W. G. iron,

**Silver Fulminate.** Silver fulminate has a composition similar to that of the mercury salt, the acid hydrogen of fulminic acid being replaced by silver instead of mercury. Its composition therefore would be represented by the formula  $\text{Ag}_2\text{C}_2\text{N}_2\text{O}_2$ .

Silver fulminate may be prepared in the laboratory as follows :

Introduce into a flask, of about 300 c. c. capacity,

Silver (granulated) . . . . . 1 part,

Nitric acid (Sp. Gr. 1.308) . . . . . 20 "

and shake gently until all of the silver is dissolved. Pour the solution thus obtained into a flask (2000 c. c. capacity) containing

Alcohol (87 per cent.) . . . . . 27 parts.

Bring the new solution to a temperature of  $212^\circ \text{F}$  by placing the flask in a vessel containing boiling water, to which additional water is added as long as the reaction continues. As soon as the solution becomes turbid, remove the flask, allow it to cool, and add

Alcohol (87 per cent.) . . . . . 27 parts,

and replace the flask in boiling water. When the reaction ceases entirely, remove the flask, allow it to cool, and wash the opaque white crystals, until the decanted wash water shows no traces of acidity. This process, so simple as described, requires the greatest care and caution. All danger of the liquid boiling over must be eliminated by the use of capacious vessels. All flame must be removed to a distance lest the vapors should take fire. The mixture must be stirred carefully, and, when dry, contact with hard surfaces must be avoided. It is generally transferred by means of paper shovels, and stored in paste board or paper boxes, or, if put in glass bottles, they should not be stoppered, but the mouth should be closed by a piece of paper with a sheet of rubber over it.

Prepared as above described, silver fulminate forms small, white, opaque, shining needles, having a strong bitterish metallic taste, and is very poisonous. It is but slightly soluble in cold water, but dissolves in 36 parts of boiling water and separates on cooling.

It dissolves much more freely in aqueous ammonia, and is left behind unaltered as the ammonia evaporates. When exposed to white or blue light it gradually blackens, giving off carbon dioxide and nitrogen, and leaving a black substance mixed with a small quantity of the decomposed salt. It explodes much more violently than the mercury salt, and under the same conditions. When dry, it explodes at a temperature of  $130^{\circ}$  C. In a moist state it requires a much harder blow to explode it than when dry, but it can be made to explode, even under water, by friction with a glass rod. When well washed, and exposed to the sun until thoroughly dry, it explodes upon the slightest touch. Except in the manufacture of detonating toys where very minute quantities are used, this salt is practically useless.

*Gold Fulminate* is a violently explosive buff precipitate formed by adding ammonia to the ter-chloride of gold.

*Platinum Fulminate* is a violently explosive black precipitate formed by mixing ammonia with a solution of binoxide of platinum in dilute sulphuric acid.

*Zinc Fulminate* is obtained by leaving zinc and water in contact with mercury fulminate, and allowing the solution to evaporate.

*Copper Fulminate* is obtained by boiling copper with water and mercury fulminate. It appears in the form of green crystals which explode violently when heated.

In addition to these salts which are formed by the replacement of all the hydrogen in the original fulminic acid by a single metal, there is another class of fulminates, which are known as *double fulminates*, in which one-half of the hydrogen is replaced by one metal and one-half by another.

*Double Fulminate of Silver and Ammonia* is obtained by dissolving the silver salt in warm ammonia. Its composition may be represented by the formula  $\text{Ag}(\text{NH}_4)\text{C}_2\text{N}_2\text{O}_2$ . This double fulminate is more violently explosive than any of the single salts, and is exceedingly dangerous even when moist.

*Double Fulminate of Silver and Potassium*,  $\text{AgKC}_2\text{N}_2\text{O}_2$ , is obtained by adding potassium chloride in excess to the fulminate of silver.

In considering the subject of the fulminates, certain other substances which, like the salts of fulminic acid, undergo, under normal conditions, a detonating explosion *only*, may very properly be included.

**Nitrogen Chloride or Chloramide.** From a chemical standpoint this is the simplest example of a detonating substance, as well as one of the most unstable of explosive bodies.

This substance was discovered in 1811 by Dulong, "who, notwithstanding the fact that he lost one eye and three fingers in the preparation of this body", yet continued the investigation of the substance. The composition of nitrogen chloride had not yet been accurately determined. It is formed when chlorine is led into a warm solution of sal-ammoniac, or when a solution of hypochlorous acid is brought into contact with ammonia. From these methods of formation, it would appear that the chloride of nitrogen is formed by the replacement of the hydrogen of ammonia by chlorine, but whether this replacement is partial or complete is an undecided question.

If we consider the replacement to take place by degrees, then three compounds would result according to the amount of chlorine substituted, thus:

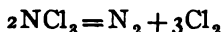
$\text{NH}_2\text{Cl}$	. . . . .	mono-chlor-amide.
$\text{NHCl}_2$	. . . . .	di-chlor-amide.
$\text{NCl}_3$	. . . . .	tri-chlor-amide.

Nitrogen chloride may be conveniently prepared by inverting a bottle of chlorine, perfectly free from greasy matter, over a leaden dish containing one part of ammonium chloride in twelve parts of water. Great care is required to obtain the chlorine in a very pure state, and the gas must be dried before it is collected by passing it through sulphuric acid.

Nitrogen chloride, or the *trichloramide*, is obtained in the form of a heavy, yellow, oily liquid (Sp. Gr. 1.65) which volatilizes very easily and yields a vapor of characteristic odor which affects the eyes. Heated to  $93^\circ \text{C}$  it explodes violently, emitting a loud report and a flash of light. Its instability is due to the feeble attraction with which its constituent elements are held together, and the violence of the explosion, to the sudden expansion of a small volume of the liquid into a large volume of nitrogen and chlorine,

and, possibly, hydrogen chloride. The explosion of this substance is at once caused by contact with substances which have an attraction for chlorine, such as phosphorus and arsenic; the oils cause its explosion, probably by virtue of their hydrogen; oil of turpentine explodes it with greater certainty than the fixed oils. Alkalies also decompose it violently, while acids having no action upon chlorine are not so liable to cause explosion. It has been distilled in the open air at  $71^{\circ}\text{C}$  without explosion.

The decomposition of the tri-chloramide may be represented by the equation



therefore one equivalent (120.5 grammes) will furnish 44.65 litres of gas, or one kilogramme will yield 370.5 litres.

On account of its constitution and properties, this substance is of great interest in the study of explosives, although practically it is perfectly useless. It differs from all other explosives heretofore considered in that it contains no oxygen, and among the products of explosion we find only elementary substances. From these facts it would appear impossible that the explosion could result from combustion. This phenomenon has been thoroughly investigated, but only within comparatively recent years has any explanation been offered that seemed satisfactory.

The old theory that *all* synthetical changes were accompanied by the development of heat, while *all* analytical changes were attended with the absorption of heat has not only been disproved, but the study of thermo-chemistry has established beyond a doubt that, in many reactions, synthetical and analytical, the contrary conditions prevail.

According to this new branch of chemical science, therefore, chemical compounds have been classified, according to the thermal phenomena attending their formation, into two classes, viz., *exothermous* bodies and *endothermous* bodies. Exothermous bodies are those whose formation is attended with the evolution of heat. Endothermous bodies are those whose formation is attended with the absorption of heat. It is obvious that all endothermous bodies must be more or less unstable, since, according to the principle of maximum work, they must constantly tend to break up into the simpler substances of which they consist.

Nitrogen chloride is a remarkable example of the endotherm-ous class, and its extreme instability and explosiveness is explained as follows :

By observing the reaction which has been assumed to represent the decomposition of trichloramide, it is seen that the nitrogen atoms unite with each other to form molecules of nitrogen gas, and the chlorine atoms unite in a similar manner to form molecules of chlorine gas, and the amount of heat evolved by the union of these similar atoms so far exceeds the loss of heat that attends the separation of the dissimilar atoms of nitrogen and chlorine, that the decomposition of this compound is attended with the evolution of 38100 gram-units of heat.

**Nitrogen iodide or Iodoamide.** This body may be made by dissolving iodine in the least possible quantity of alcohol (95 per cent) and precipitating it by pouring it into a large volume of water. The finely divided iodine thus obtained is washed several times by decantation, and then gently triturated in a porcelain mortar with a large excess of concentrated ammonia water at  $0^{\circ}\text{C}$  for several minutes, and the liquid poured off from the subsiding black powder. The ammonia is replaced two or three times by a fresh solution, and the powder is then transferred to a flask and washed thoroughly, first with alcohol (95 per cent.), then with absolute alcohol, and finally with anhydrous ether, all of these liquids being artificially cooled. After the last washing, the ether is decanted until only a fluid black mud remains, which is poured upon a filter, drained a few moments, and the remaining traces of ether removed as vapor by means of a current of cold air.

On account of its extreme sensitiveness, iodoamide is made only for experimental purposes, and to avoid accidents, it is advisable to divide the filter with the moist precipitate obtained as above upon it into small pieces, and expose them to warm, dry air at some distance from each other.

Iodoamide is a brownish-black soft powder, which, when dry, explodes from the slightest cause, producing a loud report, and destroying everything that may be near it. The explosion is attended with a faint flash of violet light, nitrogen being set free as gas, and iodine in the form of a very fine powder. It may be exploded by friction, even under water, and in the dry state it de-

tonates upon being touched with a feather, or scratched with the edge of a piece of paper. When moist it decomposes slowly in contact with the air, yielding nitrogen, iodic and hydriodic acids, while under water it undergoes decomposition in the presence of a beam of light. Like the chloride, the composition of nitrogen iodide is still a question, Colin and Gay-Lussac holding that its formula should be  $\text{NI}_3$ , that is that it is tri-iodoamide, while others claim that it contains more or less hydrogen.

**Nitrogen Bromide or Bromamide**, whose composition is probably analogous to that of the chloride, may be formed by decomposing nitrogen chloride with an aqueous solution of potassium bromide. It exists as a dense blackish-red, very volatile oil, having an odor like the chloride, and explodes violently by contact with phosphorus and arsenic.

**Nitrogen Fluoride or Fluoramide** is produced by passing an electric current through a concentrated solution of ammonium fluoride, and is deposited as oily drops on the negative plate. These drops explode violently when brought into contact with the positive pole, or with glass, silica, or organic matter.

**Silver Amine.** This substance was discovered by Berthelot nearly one hundred years ago by acting on silver oxide with ammonia.

The formula for silver amine has been shown to be  $\text{Ag}_3\text{N}$ . It explodes upon the slightest shock when dry, and even when wet it requires the greatest caution. It is supposed to have been the initial detonating agent in the bomb that killed the Czar.

**Copper Amine, or Cupricamine.** This is the copper compound similar to that just described, and is supposed to have the composition  $\text{Cu}_6\text{N}_2$ . It is formed by passing a current of dry gaseous ammonia over finely powdered cupric oxide heated to  $250^\circ\text{C}$ ; water and nitrogen gas are evolved, and the nitride is left as a dark green powder, which, when heated to about  $310^\circ\text{C}$ , explodes feebly, emitting a red light. Strong acids decompose it with the evolution of nitrogen.



**Mercury Amine.** By passing dry ammonia gas over the dry yellow mercuric oxide as long as the gas is absorbed, and then heating the resulting black-brown mass cautiously at a temperature not exceeding  $150^{\circ}\text{C}$  until water ceases to be given off, this substance is obtained. It detonates powerfully when struck or heated, and is decomposed by acids into the salts of ammonium and mercury.

**Nitrogen Sulphide.** This compound may be obtained by passing dry ammonia gas through a solution of sulphur dichloride in 10 or 12 times its volume of carbon bisulphide until the brown color of the precipitate first formed disappears. The yellow liquid is filtered from the ammonium chloride which is produced, and allowed to evaporate spontaneously, when the crystals of nitrogen sulphide are formed, mixed with sulphur. The sulphur is dissolved out by carbon bisulphide. It appears in the form of golden-yellow crystals of Sp. Gr. 2.22, and detonates powerfully under percussion, but is less sensitive than mercury fulminate. It deflagrates at  $207^{\circ}\text{C}$ , is not affected by dry or moist air, and has been heated to  $50^{\circ}\text{C}$  without undergoing change. It irritates the mucous membrane of the nose and eyes painfully, although it possesses but slight odor. It is an endothermous body, and when decomposed according to the reaction



it evolves 31900 units of heat.

In concluding this lecture there remains to be mentioned one other class of explosive compounds whose mode of action allies them closely to those which have just been described, and some of which are so highly explosive that they have been proposed for use as detonating primers.

**Azo-Compounds.** They are nitrogenized bodies called *azo-compounds* and may be regarded as formed by the replacement of two atoms of hydrogen (in two molecules of an aromatic hydrocarbon) by two of nitrogen.

**Diazobenzene**— $\text{C}_6\text{H}_5\text{—N}\equiv\text{N—OH}$ . This body may be considered as a type of this class, and may be formed by the indirect substitution of hydrogen by nitrogen in benzene. Diazobenzene

is a quite unstable substance, while the nitrate, which is employed in the arts for the manufacture of dye-stuffs, is so explosive that it has been proposed for use as a detonating primer.

According to Berthelot and Vieille, diazobenzene nitrate is the residue of two nitrogenized bodies which have lost, the one (nitrous acid) its oxygen, the other (aniline) a part of its hydrogen, in the act of combination ; but a notable portion of the energy of these elements remains in the residue, which accounts for its explosive character. If preserved in dry air out of contact with the light, this substance can be kept for two months and more, but exposed to daylight it slowly changes ; in moist air, the change is rapid, and in contact with water it is immediately decomposed. When heated to about  $90^{\circ}$  C, it detonates violently, heated slowly at a lower temperature, it gradually decomposes.

As a result of his "Researches on the Diazo-compounds", P. Greiss has obtained the para-di-tri-azobenzene, which explodes with extreme violence when heated above its melting point ; meta-midotriazobenzoic acid, which detonates when heated in the dry state ; and metaditriazobenzoic acid, which, when heated, explodes with the formation of a black cloud.



## LECTURE XX.

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### MANIPULATION, TRANSPORTATION AND STORAGE OF HIGH EXPLOSIVES.

#### **Precautions to be Observed in Handling High Explosives.**

The danger of careless handling of explosives has already been alluded to, and cannot be too strongly emphasized. Modern high explosives are justly claimed to be safer to handle than gunpowder, but there are certain rules which cannot be violated with impunity. The tremendous power developed by the explosion of even a few ounces of these explosives, renders the occurrence of small accidents highly improbable; and those whose duty it is to work with them, should remember that *no margin is left for ignorance, carelessness, or stupidity*. The very safety of the new explosives seems to lead those who have had little experience with them into over-confidence, and for all who are called upon to deal with these substances practically, it is well to remember always that "*the function of an explosive is to explode.*"

The properties of the various modern high explosives have been enumerated, and the particular danger inherent in each. It is therefore scarcely necessary to add any further words of caution with regard to handling them, and preparing them for use other than to insist upon proper respect being paid the tremendous power stored up in these substances.

In making or testing explosives, be sure that you understand thoroughly the several steps before undertaking the experiment, and during the investigation, use only so much as is absolutely necessary to attain your object. Often one gramme will answer your purpose far better than a pound, and with a correspondingly smaller disaster in case of accident. In using high explosives, deal with only the amount required for immediate use; for instance, it is not necessary to use more than a half cartridge of

dynamite in preparing a primer, therefore do not use a larger amount for that purpose. Do not stand over a box of dynamite or other explosive when preparing a primer; and when firing a charge be sure that the supply of explosives required for immediate use is well protected from the flying debris. Never carry detonators in the same basket, cart, or wagon with the explosive.

In using detonators with explosives of the "Sprengel Class," in which nitric acid enters as a principal ingredient, *it is absolutely necessary to prevent the copper case of the detonator from coming into contact with the acid*, otherwise a premature explosion is sure to occur. To avoid such accidents, coat the copper capsule thoroughly with paraffin by dipping it in a vessel containing melted paraffin, examining the coating afterwards to be sure that there is no break in its continuity.

Before using a Bickford or other time fuse, it is well to determine its rate of burning; likewise test beforehand the electric or magneto-electric exploder, when it is desired to use electricity to ignite the charge. In case of failure of a charge to explode, or to explode at the proper time ("*hang-fire*" as it is technically termed), do not hurry in seeking for an explanation for such failure. If, after waiting sufficiently long (depending upon length of fuse and other attending circumstances) no explosion occurs, an examination may, and generally should be made. If the exact depth of the tamping be known, it will generally suffice to remove the tamping to within a couple of inches of the charge, insert a new primer, retamp and repeat the attempt to detonate the charge. *In no case attempt to remove the charge.*

Nitroglycerine compounds must never be exposed to shocks or violent compression between two metals. The danger attending the thawing of frozen dynamite has been alluded to, and the proper manner in which the frozen substance may be restored to its plastic state. It is to be noted that while frozen dynamite is less sensitive to ordinary shock, friction and percussion than when in the unfrozen state, the reverse is true with regard to explosive gelatine.

In handling nitroglycerine and its compounds, keep in mind that it is an active poison, although it is dangerous only when considerable quantities are introduced into the system.

Unfortunately, the skin readily absorbs nitroglycerine ; and until the system has become accustomed to its effects, the results, which vary with the individual, are headache, vertigo, nausea, intoxication, and general lassitude, which often continue for several hours. Similar effects, caused probably by inhalation of vapor or floating particles charged with nitroglycerine, occasionally follow from working with dynamite in a close room. Good ventilation, and avoiding any absolute contact with the powder, are, therefore, precautions which usually commend themselves after a little experience. The hands should always be washed thoroughly before eating ; and it is well to use weak potash lye or strong soap, followed by a second bath in pure water. Habitual workers with nitroglycerine become proof against the injurious effects—a continuous experience of a couple of weeks being in general sufficient. The hands may also be protected by wearing rubber gloves.

No satisfactory antidote for nitroglycerine poisoning has yet been found ; cold water applied to the head, and strong coffee taken internally, are sometimes recommended. Ten to fifteen drops of aromatic spirits of ammonia have sometimes afforded relief, and, in some cases, when taken beforehand, have prevented the usual headache. The Austrian engineer prescription consists of acetate of morphia mixed with white sugar, always to be administered by a physician. A dozen doses are prepared by mixing one or two grains of the acetate with two drachmas of sugar.

As sold by the American companies, dynamite is delivered in wooden boxes, each containing 50 pounds, and unless it should be specified in the order that the powder shall be supplied loose, it will be sent in the form of compressed cartridges, which are usually preferred for blasting purposes. As the principal military use of dynamite is for the purpose of charging torpedoes, it will generally be found at posts, if at all, in the form of loose powder.

**Precautions to be Observed in Loading Torpedoes and Shell.**  
Torpedoes and shell are charged as follows : The loading should always be done in light wooden buildings, well ventilated ;

the floor should be frequently swept, and the sweepings, including paper wrappings, should be burned in the open air. Extremes of heat and cold are unfavorable conditions. No acids or alkalies should be allowed near the explosives, and above all no fuzes. The latter are as dangerous as matches in a powder magazine.

No unnecessary fire must be permitted in the vicinity. It is true that small quantities of these high explosives ignite by a spark or flame, and burn away harmlessly; but the result is different if the quantity be large enough to give time for the heat of the burning portion to raise the rest of the mass to the temperature of explosion. Disastrous accidents have been traced to this peculiarity as a probable cause; and it is, therefore, well to have no larger supply in the loading-room than is necessary for immediate use.

Particular care must be taken in loading torpedoes and shell, that none of the material remains in the screw threads. The funnels are made long enough to project entirely through the loading holes; but examination in every case should be made to see that both the male and female screw are free from particles of dynamite, before attempting to close the can or torpedo. That none of the powder should be scattered about the floor or among the tools, is self evident.

Any exudation of free nitroglycerine must be carefully avoided. It is not likely to occur at ordinary temperatures; but as with other oils, warmth promotes fluidity. For this reason a loaded torpedo must never be left exposed to a hot sun; the heat of the confined air rises to an extraordinary degree under such circumstances in a few minutes. Accordingly, the torpedo must be *placed in the shade*; or, if this be impossible, it must be *covered with blankets kept wet by frequent additions of water*.

Nitroglycerine which has exuded from its absorbent, recovers all its dangerous properties; and this rule is, therefore, imperative.

If there be any chance that the temperature of the sea water may fall below 45° Fahr., care must be taken in loading the torpedo, and especially in priming the fuze can, that the dynamite

is left loose without any packing. In this state it is certain to detonate when the fuse explodes; while if packed solid, as in cartridges, a failure might occur.

Special care is requisite that the fuses are *deeply embedded in the priming charge of the fuse can*. On one occasion, at Willets Point, a buoyant torpedo which had remained for several months in the channel failed to explode when the fuze was fired. Examination showed that the latter had been left at the top of the can, and that the constant rocking in the waves and currents had caused the frozen charge to settle fully an inch away from it; hence the explosion of the fuse, although violent enough to drive a hole through the tin can where the copper cap had chanced to touch it, failed to ignite the dynamite from want of actual contact. A second fuse, properly placed, produced a violent detonation, the dynamite still remaining frozen.

**How to Make a Dynamite Cartridge, and Prepare it for Firing with a Time Fuze.** As already stated, unless particularly specified, dynamite is delivered in bulk, and therefore it sometimes becomes necessary to make up cartridges for some special purpose. The cartridge case is readily made by rolling stiff brown manilla paper around a mandrel, gluing the last turn. One end should be closed by turning in the paper carefully or by inserting a cork in one end, clamping it and tying with a strong string. The case thus made should then be dipped two or three times in melted paraffin and allowed to dry. The powder is then weighed out and introduced into the case and compressed gently by means of a wooden tamper, and the open end closed by turning it in.

The usual method of firing dynamite cartridges is to insert a detonator or cap of proper strength, to which has been attached a piece of Bickford (or other time) fuse in the cartridge, place the cartridge where the work is to be done, tamp it or not, as the case may require, and ignite the free end of the fuse. The exact *modus operandi* is as follows:

*First.* Having determined the rate of burning, to make a primer, cut off a piece of fuse of the requisite length and insert the fresh cut end in the cap. The fuse should fit the cap exactly; if it is too large it may be pared down so as to fit; if too



small, wind it with paper until it fits. Having inserted the fuse in the cap, crimp the open end of the cap tightly on the fuse. By crimping the cap, the fuse is not only secured, but the force of the fulminate is more fully developed. If the cartridge is to be used under water, great care should be taken to make the upper end of detonator water-tight by coating it with paraffin, tar, shellac, or similar substances.

*Second.* The cap is next to be inserted in the cartridge. Open that end of the cartridge which has the longest end of paper wrap, and with a round stick slightly smaller than the cap, open a hole in the centre of the cartridge and insert the cap; now draw the paper close around the fuse and tie it securely with a string. The cap is inserted only two-thirds of its length, to avoid the possibility of the fuse setting fire to the cartridge before the spark can reach the detonator.

*Third.* If more than one cartridge is to be used, and they are to be inserted in a box-hole, they should be introduced singly and each one forced gently down with a wooden rammer so as to completely fill the hole. *An iron tamping rod should never be used.*

*Fourth.* Everything being in readiness, and every one (except the man in charge) being at a safe distance, the fuse is ignited, and the operator himself quickly withdraws.

**The Application of Electricity to Firing High Explosives.** The use of the ordinary time fuses for firing high explosives, is attended with two very serious disadvantages:

1. The numerous failures to fire at all and frequent cases of "*hang-fire*," both of which, and especially the latter, have been the cause of innumerable accidents in the past.
2. The practical impossibility of securing the simultaneous ignition of several charges, by means of which, experience has proven, double the effect is produced as when the same number of shots are fired consecutively.

At present both of these disadvantages may be eliminated by the use of electricity for igniting the charges. This subject has been very exhaustively investigated by General H. L. Abbot, U. S. Corps of Engineers, from whose report the bulk of the following remarks is taken. An electric outfit for use with high

explosives consists of electrical fuses, connecting wires, and an igniting apparatus.

**Electrical Fuses.** Electrical fuses may be divided into three classes, viz:

1. *Low Tension*, for use with strong electrical currents of low potential.
2. *High Tension*, for use with condensed sparks, capable of jumping a sensible air-space.
3. *Medium Tension*, specially designed for magneto-electric machines, which generate electricity characterized by a potential higher than the former, and lower than the latter.

Although the three great classes are thus well marked, it by no means follows that a given variety of fuse can only be ignited by a particular kind of electrical generator. While this is true for some varieties, others may be fired by electricity under any of its characteristic forms.

For example, the Abel magnet fuse, although belonging to the medium tension class, is not unsuited to frictional machines; and it may also be used with voltaic currents of high electromotive force. As a rule, however, each of the three classes of generators should be provided with a fuse specially adapted to it.

Every electrical fuse suitable for use with explosive compounds should have: 1st, two insulated conductors for conveying the current; 2d, a plug to receive and firmly hold an end of each near to, but not touching, the other; 3d, a small priming suitably arranged for ignition at this point; and, 4th, a metallic cap, containing a detonating charge, usually of fulminating mercury.

The only essential difference between the three classes lies in the manner of causing ignition. The low tension variety usually acts by the heating of a very fine wire uniting the insulated conductors, and imbedded in a suitable priming. The second and third classes are fired by the passage of the electricity through a small break in the metallic circuit at this point, the spark igniting a sensitive priming; they differ from each other in the chemical composition and the electrical resistance of this priming.

The theory usually accepted for the ignition of high tension and medium tension fuses is that the heat generated by the passage of the spark through the priming raises the temperature sufficiently to produce explosion. This view rests entirely upon analogy, no attempt having been made to verify it by experimental research; indeed, without suitable apparatus specially designed for the purpose, no precise analysis of the problem would be possible.

*Platinum Fuses.* There is a great variety of fuses belonging to each of the three classes, but a description of the platinum medium tension fuse will suffice for all. It consists of a copper capsule which has a slightly raised rim around the upper portion thrown out from the inside, so as to hold the sulphur cement more firmly in place. Two copper wires enter the capsule through the sulphur cement, which closes the mouth, and extend downwards into the chamber or body of the capsule which contains the detonating compound, generally the fulminate of mercury. The ends of the wires entering the capsule are *bare*, and are connected by means of a fine platinum wire or bridge, which is heated to bright redness by the passage of the electric current.

On the outside of the capsule the wires are insulated. At present these fuses are largely made in two parts, one containing the wires cemented as just described and a very small charge of igniting material, and the other being the ordinary blasting cap used with the Bickford fuse. The one fits snugly into the other, and by this device it is possible to substitute caps of different strength whenever necessary, by simply separating the two parts and making the change in the cap. When required for subaqueous work, the insulation is by means of gutta-percha covering. These fuses are particularly adapted to the magneto-electric igniter.

**The Connecting Wires.** Wires are employed to conduct the electricity from the igniter to the point where it is to be applied. Two lines are used, one known as the conducting wire, which conducts the current to the point of application; the other, or return wire, completes the circuit back to the igniter. Any wire that is a good conductor of electricity may be used; it is not necessary

that it should be insulated, although it is always better that it should be so. If the connecting wires are un-insulated, care must be taken they do not touch each other (so as to form a short circuit) or the ground. It therefore becomes necessary to attach such wires to poles provided with insulators. For important work, and especially when used in military operations, in which all possibility of failure is to be eliminated as far as possible, thoroughly insulated connecting wires should always be used. Everything considered, the best connecting wires for electric igniting is a perfectly clean copper wire carefully covered with india-rubber. For short distances the cotton and paraffin covered wires answer very well.

If the blast is to be a very large or important one, the wires should be suspended from poles provided with insulators as in the case with un-insulated wire ; but for short distances the insulated wires may be stretched along the ground. For all ordinary work, such as the destruction of timbers, iron or steel rails, that would be undertaken in a hurried raid, the wires may be most conveniently carried on a portable double reel, so that they can be laid or gathered in with despatch, and without danger of tangles and breaks.

In addition to these wires, there is another which is still more convenient for military purposes. It consists of two well insulated wires wrapped into a single wire by india-rubber stripping. Unless the wires attached to the fuse are at least two feet in length, it is well to join the connecting wires to the fuse wires through the interposition of the two other short wires ; otherwise the ends of the connecting wires will be constantly blown off.

To prepare the wires for a blast requires particular attention. If un-insulated wires are used, the ends should be thoroughly cleaned of any dirt, rust, or other substance that might form a coating in their surface, and then joined to the fuse-wires by bending back the ends and twisting them snugly around each other. If the wires are insulated, it will be necessary to pare off the insulating covering for two or three inches from the ends, and then proceed as in the case with un-insulated wires. If the ground is very wet, or the wires are to extend under water, it will

be necessary to protect the junction. This may be done by slipping over the wires a piece of rubber tubing, and when the wires are joined, slipping the tubing over the junction and tying the ends tightly with twine. *Never connect the fuse-wires with the connecting wires, until you are absolutely sure that the igniter ends of the connecting wires are disconnected from the machine or battery.*

**Igniting Apparatus.** Several methods of igniting electrical fuses have been devised, all of which have certain advantages and corresponding disadvantages, but after a long series of experiments conducted by General Abbot at Willets Point, it was decided that for ordinary military service, the magneto-electric machine, made by Laflin & Rand, known in the trade as "Magneto No. 3," fulfilled more of the necessary conditions than any other igniter, while it cost much less.

This machine belongs to the dynamo-electric class (frictional electricity, etc., being used in the other classes) and can be used with absolute certainty when from one to five charges are to be fired. Maximum capacity of fifteen charges is claimed for the machine under favorable conditions.

As we shall use this machine, a brief description of it is given. It is encased in a wooden case 16 by 8 by 5 inches in size, the total weight being  $18\frac{1}{2}$  pounds. A leathern strap handle, with terminals for leading wires and a firing bar arranged for external use, render the instrument portable and convenient.

The internal arrangement consists of a Siemens armature which revolves between soft iron prolongations of the cores of an electro-magnet. The electricity thus generated is transformed by a commutator from an alternating to a continuous current. The circuit passes from the commutator springs into the adjacent ends of the windings of the magnet. The back-strap ends of the windings of the two halves of this magnet are extended to the terminals for the leading wires; and thence to a brass spring and collar where, by platinum contact points, they are joined together, thus completing an interior short circuit tapped by the fuze circuit as a shunt. The magnet is wrapped with 1.76 ohms of cotton-insulated copper wire No. 18, B. W. G., and the armature with 0.92 ohms of No. 21 of the same.

The novelty of the machine lies in the mode of giving rotation to the Siemens armature, and of switching into the fuse circuit the powerful internal current thus induced. Both objects are accomplished by the firing bar, which consists of a square brass rod 14 by  $\frac{1}{2}$  by  $\frac{1}{2}$  inches, fitted with a wooden handle at one end. The other end passes down into the box. One side is provided with rack teeth engaging in a loose pinion fitted over the armature spindle prolonged. A clutch holds the pinion to the spindle when the rod is descending, but leaves it free when the latter is raised, thus restricting the revolutions of the armature to one direction only. When the firing-bar reaches its lowest position, it strikes the brass spring forming part of the interior circuit; and, if in rapid motion, the shock breaks the circuit and thus shunts the current into the fuse circuit. In passing from the top to the bottom of the box the rod causes seven and one-half complete revolutions of the armature; and if the movement be the result of a sudden and strong downward pressure, this is enough to develop a powerful electrical current.

To use this igniter, the ends of the connecting wires to be attached to the machine are carefully cleaned, and attached to the terminals by unscrewing the thumb-screws, inserting the ends through the holes and tightening the screws until they are in firm contact with the wires. The firing-bar is then withdrawn to its entire length, and when everything is ready, the fuse and charge are ignited by forcing the bar home again by a swift, uniform downward pressure, care being taken that the bar is kept strictly vertical. *The connecting wires should never be attached to the terminals until everything is in readiness for the blast.* It is advisable to disconnect at least one wire after each blast.

This form of ignitor is very compact and strong, and not liable to get out of order except through very rough usage. It may, however, become temporarily deranged through two causes:

*First.* Dust or some foreign substance may find its way between the platinum contact points. By removing the screws that hold it in place, the rear of the case may be removed and the trouble remedied by using a piece of fine emery cloth.

*Second.* Trouble may arise from the surface of the commutator becoming tarnished. In order to cleanse it, remove the rear of the case as before, and also the small pin near the lower end of the rack, and then withdraw the rack from the case. The works of the machine, with the shelf upon which they rest, are next partially removed from the case, and the springs which press upon the commutator, and the yoke which holds in place the spindle upon which the commutator revolves are disconnected. The commutator may then be cleaned with a piece of fine emery cloth.

Proper attention to these details and careful preparation of the wires and fuses saves a vast deal of trouble, and cannot be too strongly insisted upon when success is absolutely necessary, and time is to be saved.

**Transportation of High Explosives.** Provided they be of good quality, all the explosives under consideration properly packed in light wooden boxes, are quite safe against any shock to be expected in ordinary or even rough handling, whether shipped on railways or steamers. If decomposition or exudation of free nitroglycerine has occurred, this is no longer true. Where the tests before starting have shown that the nitroglycerine is in good condition, neither of these dangers is to be apprehended, *unless the temperature be allowed to rise to an excessive degree.* This matter, therefore, should always receive attention. On steamers, a well ventilated place remote from the engines should be selected ; and on railways, if the weather be hot, good ventilation and ice in the car, so that no water can reach the explosive, are useful precautions.

On the other hand, it is desirable to prevent freezing to avoid the inconvenience of thawing. In winter, therefore, care should be taken to protect the boxes against exposure to low temperatures. Packing in straw or sawdust may be useful.

Under no circumstances should cases of fuses be placed in the same car, or anywhere in the vicinity of the explosive.

Water should always be kept away from dynamite and Atlas powder, to prevent a possible exudation of nitroglycerine ; with cartridges this precaution is highly important. In the case of a conflagration, there is usually no danger of explosion with small quantities of high explosives ; but this is far from true with large

quantities. In an official trial in England, a mass of 672 pounds of dynamite No. 1, exploded after burning fiercely for a few minutes.

**Rules of the Pennsylvania Railroad Company, Concerning the Transportation of Explosives Over its Lines.** In this connection it is deemed expedient to consider the rules issued by the Pennsylvania Railroad Company, concerning the transportation of explosives over its system of lines.

High explosives such as Atlas, Giant, Hércules, Dittmar, Commercial, Hecla, and other nitroglycerine powders, will be received for shipment only under the following conditions:

*First.* Shipments to be placed in strong boxes, not too large to be readily handled by one person, and each package to be plainly marked "Explosives—Dangerous" on top, and on one end.

*Second.* It is understood that in these articles the nitroglycerine is thoroughly absorbed in charcoal, sawdust, infusorial earth, wood-fibre, carbonate of magnesia, or other similar substances, and that the amount of nitroglycerine is such that the temperature of the hottest summer day will not occasion leakage. Should any package show outward signs of any oily stains, or other indication that absorption is not perfect, or that the amount of nitroglycerine is greater than the absorbent can carry, the package must be refused in every instance, and must not be allowed to remain on the property of the company.

*Third.* Nitrate and other explosive preparations, not in accordance with the above specifications (except ordinary black powder), will in no case be received for shipment.

*Fourth.* Shipment must be loaded so as to lie bottom side down, it being understood that the cartridges are so placed in the boxes that they will lie on their sides, and never on their ends when so loaded. The boxes must be so placed in the car, that that they cannot fall to the floor under any circumstances.

*Fifth.* Shipments of common black powder may be received if packed in good substantial iron or wood kegs. Packages not to exceed one hundred and fifty pounds in weight, unless for export, will be received.



*Sixth.* In no case will percussion caps, exploders, safety squibs, fulminates, friction matches, or any other articles of like nature be loaded in same car with any of the above explosives. There cannot be too great care exercised in this matter.

*Seventh.* Safety fuse will be received for shipment at any time it is offered, and the restrictions in regard to shipping powder do not apply to it.

*Eighth.* As the special powder cars will be taken out of this service, agents must know that none of the above explosive substances are loaded at their stations in old cars having loose boards, or cracks in the roof or sides. Cars for carrying these explosives must be first class in every respect, must be tight everywhere, and must have doors that can be closely shut, leaving no cracks for sparks to get in. When in full car loads the doors must be stripped.

*Ninth.* Every car containing any of the above explosive substances, either full car load or small package, must be plainly marked on both sides, "Powder—Handle Carefully," so that those having charge of it will not do anything ignorantly to incur danger. This should be done by the shipper of full car loads, and by the agent when the packages are loaded in car at his station.

The rules apply with equal force to the transportation of explosives, either by rail or by wagon transport during active service, and are to be carefully read with that object in view.

**Storage of High Explosives.** At military posts high explosives are best stored in ordinary service magazines, over which are erected light wooden roofs so as to insure a draught of air during the hot summers. Before placing the boxes containing the high explosives in the magazines, they should be given a coat of paint or shellac to protect them from moisture. Damp air, except with Atlas powder, is not injurious.

The boxes should be placed on skids and the space between the skids partially filled with sawdust to absorb any nitroglycerine which might exude from the powder.

The boxes should be turned over every month or two, and if kept long on hand, they should be opened and the powder tested from time to time in the manner already described. The usual precautions against fire should be taken; and if any powder be spilled on the floor, or nitroglycerine exude and be absorbed by the sawdust, it should be removed at once and burned.

No fuse, caps, or detonators of any kind should ever be allowed in the same magazine with the explosives, but should be stored in a separate magazine, or dry frame building. The magazine should be located in the most unfrequented part of the fort, and the contents plainly marked on a prominent part of the building.

The precautions in the storage of ordinary gunpowder, and the care of powder magazines already noted, apply with equal force to the storage and care of high explosives.



## LECTURE XXI.

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### THE USE OF HIGH EXPLOSIVES FOR MILITARY PURPOSES, AND THE RELATIVE FORCE OF EXPLOSIVE BODIES.

Modern explosives have been frequently used in the Engineer and Artillery branches of the service. Special works give very complete information about these military operations, and enumerate various experiments with gun-cotton and dynamite conducted since 1870.

On account of the limited time at our disposal, we shall confine ourselves to indicating briefly some of these operations, and shall endeavor to show the important part which the new high explosives have been called upon to play in artillery, on land and sea.

The explosion of mines executed by military engineers may be divided into two classes, according as they are planned before hand or executed hurriedly and without previous calculation. In the first case the preparatory steps are carried out with great precision, and the amount of explosives used are only those absolutely necessary to accomplish the object in view.

In the second case, on the contrary, it is necessary to act rapidly and to produce the greatest possible effect ; the principal factors are economy of time and absolute certainty of success, while the question of expense is entirely secondary.

Formerly for explosions planned beforehand, black powder, which has a greater propelling force and is less destructive and less costly than high explosives, was used. For demolitions and hasty destructions, cotton powders and dynamites which are more powerful, occupy less space, and are more easily transported and put in place, are now preferred.

**Conditions to be Fulfilled by a Military Explosive.** An explosive for military purposes must satisfy the following conditions :

- 1st. It must be very powerful.*
- 2d. Insensible to the shock of projectiles.*
- 3d. It must be plastic.*
- 4th. It must be easily and safely exploded.*
- 5th. It must be as stable as possible, so that it can be kept without alteration when in damp places.*

A few experiments easily conducted and the ordinary tests for stability are sufficient to verify approximately if these conditions are fulfilled.

The principal objects of hasty explosions executed by military men are the cutting down of trees, the destruction of pieces of wood or iron, the demolition of doors, bridges, and walls ; the destruction of rails, iron plates, cannon, etc.

**The Cutting Down of Trees.** It may frequently happen that trees are to be felled quickly, either to clear the space around a defensive work, or to strengthen a position by means of an abattis or for various other reasons. For the rapid execution of such work, time and labor may be saved by the use of high explosives. To fell a tree the charge may be located in one of three positions, viz :

1. *The charge may be placed in a circle, around and on the outside of the trunk.*

In this case, having determined the height at which the tree is to be cut down, the weight of charge (for gun-cotton and gum-dynamite) is determined by the formula,

$$P = 0.0014 d^2.$$

In which P represents the weight of the charge in kilograms and *d* the diameter of the tree in centimetres at the plane of section.

2. *The charge may be placed on one side of the tree.*

In this case, the weight of charge for the same explosives is determined by the formula,

$$P = \frac{5}{4} (0.0014) d^2.$$

3. *The charge may be placed in holes bored horizontally into the tree.* In this case the weight of charge is determined by the formula,

$$P=0.0002 d^2.$$

This method is by far the most economical, if we consider the amount of dynamite required, but it requires more time and a heavy auger to prepare the charge for firing.

One or more holes are bored into the tree according to the weight of the charge, which must always penetrate to the center of the tree.

In addition to the foregoing formulæ, the operation of felling trees may be accomplished without calculation as follows: About one foot and a half above the ground, and with a wood-auger of one inch and a half in diameter, a radial hole is bored into the tree to a distance of two-thirds of its diameter; and the charge is pressed down tightly with a wooden ramrod, so that the explosive closes and fills the cross-section completely. Having placed the primer in its place, the hole is either left open or sawdust or clay is used for tamping.

Trees from nine to twelve inches diameter are blown down by boring one and one-half inch holes, having a depth of two-thirds of the diameter of the tree; and the hole is loaded to one-third of its depth.

The bore-hole in trees from twenty to twenty-four inches in thickness, should have a depth of three-fourths of the diameter of the tree, and the charge should occupy half the length of the bore-hole.

Should the trees to be blasted have a diameter of twenty-four to thirty inches, then two bore-holes should be made.

**The Destruction of Wooden Beams and Palisades.** To destroy logs with the bark on, partially dressed, the formulæ already given hold good.

If a beam of rectangular section is to be destroyed, the charge is placed in the form of a flat band, extending the entire width of the beam, and the size of the charge is calculated by the formula,

$$P=0.0003 e^2 \sqrt{b}$$

In which  $b$  and  $e$  represent the width and thickness of the beam in centimetres and  $P$  the weight in kilograms.

To destroy a *palisade*, for example, 25 millimetres thick, the charge is placed on the ground at the foot of the pickets, and is calculated at the rate of 1.25 *kilo per running metre*.

**The Demolition of Doors.** To destroy a doorway, 18 to 20 kilograms of gun-cotton or other explosive of equal force is used. The charge enclosed in a sack is suspended in the middle of the door by means of a nail or hook, or a pick-axe driven into the door. The charge of powder (ordinary) capable of producing the same effect should be from two to three times greater, and instead of being suspended, should be placed at the bottom of the door.

**The Destruction of Railway Tracks.** A charge of from 14—17 grams of dynamite or explosive of equal force, is sufficient to break an ordinary rail.

The charge in the ordinary form of a cartridge, or flattened if necessary, is attached by means of a copper or iron wire between the upper and lower flanges of the rail.

A party of eight trained men can destroy from two to three kilometres of track in one hour. The charges already prepared with Bickford fuses and fulminate caps attached are carried in wheelbarrows.

**The Destruction of Iron Bridges.** To destroy an iron lattice bridge by means of gun-cotton or dynamite, the charge is placed upon the lower girders near an abutment, and at the point where the thickness of the plates is least. If the sections are uniform throughout the length of the bridge, the charge is placed at the centre of a span between two piles. When the plate bridge is built entirely of iron plates, the simplest way is to place the charge upon the top of the beams.

**The Demolition of Stone Walls and Bridges, and of Brick Columns.** In a detached wall, to effect a break having a length twice the thickness of the wall, the weight of charge is calculated by the formula,

$$P = 2.40 e^2,$$

provided that the explosive is placed *at the foot of the wall* without mining. In this formula  $P$  represents the weight of charge in kilograms, and  $e$  the thickness of the wall expressed in metres.

If time is available, it is better to dig at its base *a mine half through the wall* and place the explosive in it. In this case the following formula gives the weight of charge:

$$P = 1.20 e^2.$$

To destroy the *arch of a bridge*, the charge should be placed at the crown and the amount calculated by the formula,

$$P = 2.40 e^2.$$

To destroy a *brick column* with a charge placed at its base, use the formula,

$$P = 3.20 e^2.$$

The values of  $P$  given in the above formulæ are exaggerated, but it must not be forgotten that in military operations the principal objects are celerity of action, and the production of the maximum effect.

**Destruction of Pieces of Artillery.** To destroy a field or siege gun, a charge of from 45 to 50 grams of gun-cotton or dynamite exploded in the bore near the muzzle is sufficient.

Either the wheels or the carriage may also be destroyed by using small charges of either of these explosives. If it is desired to break a cannon into small pieces, the piece is buried in the ground muzzle upward, and on a line with the surface. Two charges attached to a wooden rod are then placed in the bore. The charge required to produce rupture is divided into two parts, one of which is double the other. The greater is placed at the base of the bore and the other suspended at the height of the trunnions. The bore is filled with water and the muzzle closed with a wooden tompion, through which pass the conducting wires which lead to the electric detonators, by means of which the charge is exploded. In Austria, the rupturing charge is calculated at the rate of one gram of explosive to every cubic centimetre of volume of the bore. In France, one gram of explosive is taken for each kilogram of weight of the piece.

The use of high explosives as bursting charges for shell will be considered later.



**Champion's Experiments with High Explosives during the Franco-Prussian War.** M. Champion of the French Artillery Corps, furnishes the following valuable information, which he gathered during a series of practical trials in the siege of Paris by the Prussians.

*Destruction of Palisades.* The palisade which was constructed in view of the experiment had a length of one metre, and was of the ordinary model.

At the base, a cartridge containing five pounds of fifty per cent, dynamite was placed. The explosion destroyed all the stakes, and the fragments were projected in all directions.

Complete rupture of palisades of the ordinary model were produced by exploding cartridges charged with four pounds of dynamite, and suspended at their ends from the palisades. The same effect was also produced by zinc tubes containing five and a half pounds of dynamite per running metre, placed at the foot of the palisades.

In the first explosion, out of fourteen stakes, nine were cut at the height of the cartridge ; five were injured more or less without being thrown down. In the second explosion, five stakes which were in front of the cartridge were cut away.

The fact was also established in the second explosion, that no splinters were thrown in the direction of the operator.

*Doors and Wooden Enclosures.* Small cartridges, weighing three to four ounces were hung up on nails along the walls, about four inches apart. By exploding one of them, the other cartridges exploded simultaneously along the whole line.

The weight of the cartridges varied with the thickness of the obstacles.

Tamping, in both cases, would diminish the quantity of explosive used, without modifying the result. Sacks of earth, or any débris can be employed for tamping.

*Trials on Walls.* The third series of experiments was made on a wall two feet high and one and a half feet wide, constructed of rough stone masonry, joined by good mortar, and forming regular layers in the lower part.

The wall, covered with a coping of flagstone, was very solid, and made of the very best kind of material, and could be considered as a very substantial structure.

A can containing three kilograms eight hundred grams of fifty per cent. dynamite was placed vertically at the foot of the wall, and the cap was introduced through the cork-stopper, and the charge fired. A gap of eighty centimetres wide and eighty-five centimetres high was opened at the foot of the wall. The same aspect of the opening was noticeable on both facings of the wall.

The rocks flew in both directions, so that, with a small hammer, it was enlarged to an opening of one metre fifteen centimetres high, and one metre seventy centimetres wide.

A second trial was made under the same conditions, but covering the can of explosive by four sacks filled with sand. The effect was notably increased; and the breach made was one metre seventy centimetres wide by two metres forty centimetres high, and the base of it was covered with rocks to a height of seventy centimetres. The wall was shaken to the top, and two metres fifty centimetres in width.

The sacks of sand were projected to a distance of twenty-five metres back of the explosive, and some boulders were sent flying to a distance of sixty metres in front of it.

Therefore the tamping augmented very largely the effects of dynamite; but the weight of the sacks renders them inconvenient to carry, especially when in the presence of an enemy, and when the work has to be rapidly executed.

In the third trial, the object in view was to determine the most advantageous method for placing the dynamite can against the wall, without being obliged to cover it with sand. It was placed against the wall, on a slab about seventy centimetres high, and was fired without any other preparation.

The breach about fifty centimetres above the ground, presented an opening of eighty centimetres in width and one metre in height on the face against which the explosive was placed, and one metre by one metre fifty centimetres on the opposite side.

The wall was also shaken two metres high and two metres wide, and the breach could be enlarged by hand. There is, according to this trial, a great advantage in raising the charge of dynamite about one-third of the height of the wall, instead of placing it on the ground.

A fourth experiment was made to substantiate an experiment previously made by M. Champion.

He had established the fact, that when a charge of dynamite is placed against one of the walls in the interior of a room, only one breach in this wall is made, whereas the three others are thrown down; on the contrary, if the charge is placed in the middle of the room, the four walls would tumble down. The question naturally arose, if it would not be advantageous to place the charges at some distance from the wall which it was desired to destroy.

Four kilograms of dynamite, in two canvas sacks, were placed on a little earth-knoll about fifteen centimetres high and fifty centimetres from the wall, and surrounded by small sacks full of earth, but open against the face of the wall. The explosion produced only a small breach, fifty centimetres by fifty centimetres; but the wall was shaken up to its full height and three metres in width. The slabs on the coping of the wall were displaced. With very little exertion, and without tools, all the shaken part could be taken down.

Probably enclosure walls, which are generally of poor masonry, can be best destroyed in this manner.

The quantity of the dynamite charge should be in proportion to the solidity of the wall.

The less solidity a wall possesses, the more difficult it will be to throw it down, or to make a breach in it; as a bad wall gives way easily to the breaking effect of the explosion, and propagates the shock but little. The charge is therefore placed at a greater distance, and has a chance to act on a greater surface: and, owing to the bad construction of the wall, it will throw it down.

A fifth experiment was made.

In a box twenty-four centimetres by fourteen centimetres, four cartridges of dynamite were placed, each cartridge weighing seventy-five grams; and they were placed at one metre thirty centimetres above the ground. The explosion opened a breach sixty centimetres by thirty centimetres opposite the charge, and seventy centimetres by ninety centimetres on the other side of the wall.

The shock also fissured the wall, so as to enlarge the opening to one centimetre by eighty centimetres, one metre above the ground. In fact, all the experiments were conclusive in favor of the employment of dynamite in preference to gunpowder, when it is desired to produce quick effects.

Its weight is very small as compared to that of powder required to produce the same effect, and the charge need not be tamped to give satisfactory results. Consequently without fatigue, a sapper can carry to great distances all that is required to make a breach in a wall for giving passage to a whole regiment if necessary.

*Destruction of Walls at Buzenval.* The enemy was entrenched behind the enclosure of the park. A first explosion produced a breach. The operation presented great difficulties. The men who had to carry the explosives were few in number. Nevertheless, some soldiers and men of the engineering-corps volunteered under the directions of M. Pellet, and approached the indicated spots, and, by means of canvas sacks containing two kilograms of dynamite, made openings which permitted some soldiers to pass through. The walls were thin, and it was only necessary to fire the charges without tamping to open these breaches.

*Destruction of Houses. First.* In a small dwelling at Drancy, about twelve feet wide, four kilograms of dynamite were placed inside the building and against the wall.

Doors and windows were left open. The house was thrown down without projection of building material, and only the wall against which the dynamite was placed remained standing, although the walls were cracked and fissured.

*Second.* Stone cabin at Bobigny.

Thickness of wall, thirty centimetres. Four kilograms fifty per cent. dynamite, the same as in the preceding example, were placed in a corner which seemed to offer the most resistance, opposite the door.

The cabin was completely destroyed, and the rocks went flying in all directions.

It is preferable, in destroying buildings, to place the charge in the middle of the room, as an even pressure is exerted on the surface of the exploding chamber; experience has confirmed this theory.

**The Relative Force of Explosive Bodies.** The formulæ just enumerated for the accomplishment of various kinds of work are entirely empirical, and are true only for gun-cotton and gum-dynamite. In order to apply them to other explosives, they must be considerably modified, and this step is attended with very great practical difficulties. As already stated in Lecture IV, the various methods devised as yet for determining the comparative strength of explosives are mere approximations, while the difficulties surrounding the establishment of an absolute scale of force for high explosives, have not yet been surmounted.

In practical work performed at the U. S. Artillery School, a fair degree of approximation was obtained by referring to the following table, which was established by means of the Quinan Pressure Gauge :

NAME OF EXPLOSIVE.	COMPRESSION OF CYLINDER.	ORDER OF STRENGTH.
I		
Explosive Gelatine..... (Made from nitroglycerine after the Vonges Process.)	0''.585	106.17
II		
Hellhoffite .....	0''.585	106.17
III		
Nitroglycerine..... (Made Nov. 19, 1889, tested Jan. 6, 1890.)	0''.551	100.00
IV		
Nobel's Smokeless Powder.....	0''.509	92.38
V		
Nitroglycerine..... (Made Jan. 29, 1890, and test- ed on the same day. U. S. N. Torpedo Station Process.)	0''.509	92.37
VI		
Explosive Gelatine..... (Made from the last nitro- glycerine.)	0''.490	88.93
VII		
Gun-cotton..... (U. S. N. Torpedo Station, Lot 100, 1889.)	0''.458	83.12
VIII		
Gun-cotton..... (Stowmarket 1885.)	0''.458	83.12
IX		
Nitroglycerine..... (Made according to the French process and tested on the same day.)	0''.451	81.85
X		
Gun-cotton..... (Made in Artillery School Laboratory.)	0''.448	81.31
XI.		
Dynamite No. 1.....	0''.448	81.31
XII		
Dynamite de Trauzl.....	0''.437	79.31
XIII		
Emmensite.....	0''.429	77.86
XIV		
Amide Powder.....	0''.385	69.87
XV		
Oxonite..... (Picric acid fused before be- ing added.)	0''.383	69.51
XVI		
Tonite.....	0''.376	68.24
XVII		
Bellite.....	0''.362	65.70

NAME OF EXPLOSIVE.	COMPRESSION OF CYLINDER.	ORDER OF STRENGTH.
XVIII		
Oxonite .....	0''.354	64.24
(Picric acid not fused.)		
XIX		
Rack-a-Rock.....	0''.340	61.71
XX		
Atlas Powder.....	0''.333	60.43
XXI		
Ammonia Dynamite.....	0''.332	60.25
XXII		
Volney's Powder No. 1 .....	0''.322	58.44
XXIII		
Volney's Powder No. 2 .....	0''.294	53.18
XXIV		
Melinite .....	0''.280	50.82
XXV		
Silver Fulminate.....	0''.277	50.27
XXVI		
Mercury Fulminate.....	0''.275	49.91
XXVII		
Mortar Powder .....	0''.155	28.13
(Dupont.)		

While the foregoing table gives correctly the *order of strength* of the various explosives contained in it, it cannot be said to give their actual *relative strengths*, since it was, for reasons given, impossible to arrive at their absolute strengths, expressed in any unit of force. The true relations existing between them would be expressed by the relative amounts of work required to compress the cylinders to the lengths shown in the second column, and, as already shown, the greater the amount of compression, so much greater the ratio for each additional  $\frac{1}{1000}$  of an inch of compression.

While, as already stated, a fair degree of approximation was obtained from these results, still the question of the absolute force of explosive bodies remains undecided. Efforts are now being made at the Artillery School having this object in view, and it is believed that an absolute scale of force will soon be established.

The following results were obtained by Trauzl in his investigations on this subject. In his experiments which were conducted in a manner not unlike that pursued at the Artillery School, the lead cylinder measured 20 cm. in diameter and 20 cm. in height ;

the charge consisted of 20 grams of the explosive, and the detonator contained 0.4 gram. of mercury fulminate :

NAME OF EXPLOSIVE.	COMPOSITION.	RELATIVE STRENGTH.
Nitroglycerine.....	Water Free.	100
Explosive Gelatine.....	{ Nitroglycerine, 93 pts. { Soluble gun-cotton, 7 "	100
Gelatine Dynamite, No. 1.	{ Nitroglycerine, 58 " { Soluble gun-cotton, 2 " { Saltpetre, 28 " { Cellulose, 12 "	70
Dynamite, No. 1.....	{ Nitroglycerine, 75 " { Kieselguhr, 25 "	70
Gelatine Dynamite, No. 2.	{ Nitroglycerine, 38.8 " { Soluble gun-cotton, 1.2 " { Saltpetre, 45 " { Cellulose, 15 "	52
Dynamite, No. 2.....	{ Nitroglycerine, 25 " { Saltpetre Powder, 75 "	40
Mercury Fulminate.....	Alone,	22

In a resumé presented to the Philosophical Society of Glasgow in 1883, Mr. George M'Roberts, F. C. S., gave the results of his investigations on "nitroglycerine, dynamite and blasting gelatine," which included the following data :

NAME OF EXPLOSIVE.	COMPOSITION.	RELATIVE STRENGTH.
Explosive Gelatine.....	{ Nitroglycerine, 93 pts. { Soluble gun-cotton, 7 "	1400
Nitroglycerine .....	.....	1270
Dynamite, No. 1.....	{ Nitroglycerine, 75 " { Kieselguhr, 25 "	900
Dynamite, No. 2.....	{ Nitroglycerine, 18 " { Saltpetre, 71 " { Charcoal, 10 " { Paraffin, 1 "	531
Gun-cotton .....	.....	462
Mercury Fulminate.....	.....	307

In these experiments Mr. M'Roberts used a pendulum mortar, the charge being 10 grams of the explosive. This method is obviously applicable only to those explosives which detonate.



The investigations referred to were conducted practically in closed vessels, surrounded by no other medium than the atmosphere.

For use under water, and especially in the application of various explosives to a system of submarine mines, General Abbot, of the Engineer Corps, has made a most thorough and exhaustive investigation.

The limited time at our disposal, precludes a close analysis of General Abbot's methods, and we can only allude to the results obtained, and refer to his "*Report upon experiments and investigations to develop a system of submarine mines for defending the harbors of the United States*" for fuller particulars.

As a result of his investigations the following table has been compiled :

NAME OF EXPLOSIVE.	PERCENTAGE OF NITROGEN.	RELATIVE INTENSITY OF ACTION.		
		DOWNWARD.	HORIZONTAL- ALLY.	UPWARD.
Dynamite No. 1*.....	75	100	100	100
Gun-cotton .....	.....	81	87	91
Dualin.....	.....	116	111	108
Rendrock .....	20	67	78	84
“ .....	40	91	94	95
“ .....	60	93	95	96
Dynamite No. 2.....	36	75	83	88
Vulcan Powder No. 1. ....	30	66	78	83
Vulcan Powder No. 2.....	35	72	82	86
Mica Powder No. 1.....	52	74	83	87
Mica Powder No. 2.....	40	39	62	73
Nitroglycerine.....	100	71	81	86
Hercules No. 1.....	77	109	106	105
Hercules No. 2.....	42	74	83	87
Electric No. 1.....	33	51	69	77
Electric No. 2.....	28	38	62	72
Designolle.....	.....	50	68	77
Brugere.....	.....	71	81	16
Explosive Gelatine.....	89	125	117	183

\*Dynamite No. 1 was taken as the standard of comparison.

The subjects of both the absolute and comparative strength of explosives are still undecided, and until further authentic investigations are instituted, the values given in the above tables will have to be accepted.

## LECTURE XXII.

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### THE USE OF HIGH EXPLOSIVES IN SHELL.

Among the many practical uses to which high explosives may be applied for military purposes, is that of bursting charges in shell

It hardly comes within the province of these lectures to consider the many special machines which have been devised to throw large masses of various high explosives, contained in specially constructed projectiles, but a brief resumé of the attempts that have been made to fire either the ordinary or special shells from powder guns, may prove of material assistance to us.

**Experiments with Shell charged with Gun-cotton.** Attempts to use gun-cotton as a bursting charge for shell were made as early as 1864, when under the direction of the English Gun-cotton Committee, twenty-five rounds were fired with unfused shell, charged with dry, long staple gun-cotton.

The first ten rounds were successfully fired from a 10-inch smooth bore ; the next ten rounds were fired from a 13-inch mortar with like success. But of the last five rounds which were fired from a 7-inch B. L. Armstrong, two of the shells burst, one just beyond the muzzle, and the other (last) within the bore, and injured the gun to such an extent as to render it unfit for further service.

It was believed that these explosions were due to the compression or friction produced by the "setting up" of the comparatively loose charges at the moment of starting.

In 1867 experiments were resumed with compressed pulped gun-cotton. Two steel shell compactly filled with disks of gun-cotton were fired from an 8-inch shunt gun, the first bursting after one graze on the range ; the second bursting in the bore, shattering the chase and leaving nothing in front of the trunnions.

During the same series of experiments, one round was fired from a 7-inch M. L. Woolwich gun. The shell burst in the bore, cracking and expanding the gun which however remained entire. In these experiments ordinary shell were used, the only precaution observed being the wrapping and packing of the explosive.

In 1882 similar experiments were instituted in Germany, to determine the possibility of using large charges of gun-cotton in projectiles for the 21-centimetre mortar. The shell were of cast-steel with very thin walls and five calibres in length. Apparently these experiments were successful, since at present gun-cotton shell which are made in two parts are used in this mortar. These shell consist of a head and body which are secured together. The charge which is enclosed in a zinc or iron box, consists of compressed gun-cotton disks 5 cm. thick, and containing 20 per cent. of water. The upper disk is provided with a cylindrical cavity to receive a primer of dry gun-cotton, which in turn is perforated to receive the detonator. When the charge is placed in the box a wooden rod is inserted in the detonator hole, and melted paraffin is poured in to fill the insertion of the detonator. To load the shell, the charge is introduced into the box as indicated, and the box placed in the shell and the head of the latter screwed on. A hollow screw is inserted in the eye of the shell to hold the box in place, and finally, immediately before being placed in the gun or mortar, the fuse and detonator are inserted in the aperture in the screw.

These projectiles have given good satisfaction, not only in the 21-cm. mortar, but also in the 15 and 28-cm. pieces.

This projectile is similar in nearly every particular to the one recently invented by Von Forster & Wolff, in which granulated gun-cotton is used.

The further record of experiments conducted by the German Government, refers more to the action of the fuses used with shell charged with gun-cotton, than to investigating the possibility of extending the use of such bursting charges to guns of larger calibre and rifled pieces.

In this country, however, the importance of this latter line of investigation was recognized, and in 1884, Commander Folger, U. S. Navy, succeeded in firing fifteen rounds of gun-cotton at a range of 200 yards with the 80-pounder B. L. Rifle, using full charges of powder. The shell were filled with gun-cotton saturated with water, and no precaution was taken to relieve the shock upon the first impulse, beyond placing a layer of oakum one quarter of an inch thick in the base of the shell. In loading these shell the ordinary service disks were broken up in order to introduce the explosive through the fuse hole, the density was consequently greatly reduced.

These experiments were followed by others, conducted at the U. S. Naval Torpedo Station, to test thoroughly the safety of the service gun-cotton as bursting charges for *fused* shell fired from service guns under service conditions. Unfortunately the only guns available for these experiments were Dahlgren 24-pounders and 20-pounder M. L. Rifles.

Special shell were made for the tests. For trial with the 24-pounders they were of cast-iron, fitted with base plugs and ogival heads, and had an exterior diameter of  $5\frac{3}{4}$  inches, interior diameter of 5 inches and length of 8 inches. The space between the disks and the walls of the shell was well filled with fine sawdust and rammed. Full service charges of powder were used in the tests.

In the first four rounds from this gun, the shell charge consisted of three and one-half disks of wet gun-cotton, weighing  $4\frac{1}{2}$  pounds for each, the loaded shell weighing 30 to 32 pounds.

The first shot was fired point blank at the masonry escarpment of the fort on Rose Island, 50 yards distant from the muzzle. The shell was broken up and the gun-cotton scattered but no explosion followed.

The second shot fired under similar conditions, struck in the crevices of the masonry and buried itself in the earth behind the wall. It was recovered intact, except that a fragment was broken from the projecting base-plug, and was fired again (fourth shot) at the butt, the result being similar to that of the first shot.

The third shot was fired up the bay, and although it ricocheted along the water, it neither exploded nor broke up.

The fifth shell was loaded with one dry and three wet disks ; the sixth with two dry and two wet ; and the remaining four were charged with four dry disks each.

These last shots were all fired into the escarpment, and although the shell broke up on impact there was no explosion, either in the gun, during flight, nor upon impact.

The shell used with the 20-pounder were made of four inch steel tubing, one quarter of an inch thick, fitted with conical heads and movable base-plugs, and were of such diameter that the disks fitted them snugly without packing. The only precaution against the initial shock was the placing of an asbestos gasket over the base-plug. The full service charge of powder was used, and all other service conditions observed.

The first four shell were loaded with from 4 pounds 9 ounces to 6 pounds 6 ounces of wet service gun-cotton, and fired into the butt with the result that there was no explosion, the shell, however, being distorted and crushed, but still containing some of the explosive, the rest being scattered around.

In the five following shots the shell were loaded with thin ( $\frac{1}{2}$  inch) disks made by splitting the ordinary disks, and the gun-cotton was dry. The result of the fifth shot was identical with those preceding, but the last five shell broke up in the gun without explosion of the gun-cotton or damage to the piece.

These experiments were continued at the U. S. Naval Ordnance Proving Grounds, where six shots were fired from a 6-inch B. L. Rifle. The projectiles were elongated shrapnel cases with moveable heads. As in the experiments already recorded, it was proven beyond a doubt that it was possible to fire shell loaded with gun-cotton, wet or dry, from the ordinary powder guns, using service charges and under service conditions.

**Experiments with Shell charged with Nitroglycerine.** During the year of 1885, a curious and novel device of Mr. C. P. Winslow was tested by the Naval Ordnance Board. The device was a high explosive shell, so arranged that the bursting charge—*nitroglycerine*—was to be made during the flight of the projectile, and fired upon impact, either by shock or by means of a specially prepared fuse.

The shell consisted of two glass jars, one within the other, the inner one containing a mixture of nitric and sulphuric acids in the proportions by volume of 4:3, and the outer one glycerine and sulphuric acid in the proportions of 6:1; the two jars containing equal volumes of the mixtures. These jars were fastened together by means of screw caps and introduced into a tin cylinder, which in turn was placed within the shell proper. The shell itself consisted of two sections which were securely joined after the cylinder containing the jars had been inserted. Rupture of the jars at the time of firing was prevented by transverse bars in the shell to which the exterior jar was securely fastened by means of rubber bands.

To cause the shell to explode at any point of its flight, a time fuse properly cut ignited a priming of rifle powder, and forced a plunger contained in the rear section of the shell violently forward, thus breaking the jars. The rotation of the shell and broken glass were then supposed to mix intimately the contents of the jars, thus forming nitroglycerine, which was exploded by shock upon impact, or, if that failed, by means of a secondary charge of rifle powder contained in an axial chamber of the plunger.

Experiments with this device proved very unsatisfactory and the shell was condemned. In 1887 the Smolianinoff method of firing nitroglycerine from powder guns was tested at the Naval Torpedo Station. The nitroglycerine was first rendered insensitive by treating it with liquid, the character of which was kept secret, and then completely filling the shell with the explosive, and inserting a burster to which was attached a time fuse. The 24-pounder howitzer was used, and twenty rounds were fired with the service charge of powder. The shell held from one to one and one-half pounds of the liquid, which contained 97 per cent. of nitroglycerine.

Five shells were unfused and fired into a masonry wall, fifty yards distant from the gun, with the result that all were broken up but apparently without explosion. The remainder were fired up the bay, and, with the exception of three, they exploded in mid air at the time fixed, with a sharp report scattering the fragments of the shell over a very wide area.

Previous to these experiments the inventor claimed to have fired, without accident or premature explosion of any kind, over 300 shell from a condemned 20-pounder Parrot Rifle.

During the same year these experiments were repeated before the Army Ordnance Board at Sandy Hook with equal success. In these latter trials, the shell weighing from 82 to 89 pounds, and containing from 4.1 to 4.6 pounds of the prepared nitroglycerine, were fired from a 100-pounder Parrot Rifle. At the conclusion of the Newport trials, the Navy Board reported that the Smolianinoff method of firing nitroglycerine from ordinary powder guns was feasible, and recommended that further experiments be made to test its value for guns of greater calibre.

**Experiments with Shell charged with Dynamite.** In 1867 shell charged with dynamite were successfully fired in Sweden from an 18-pounder howitzer, with about two pounds of gunpowder. Three years later, during the winter of 1870-71, similar experiments were undertaken in Germany with a 6.8 inch Krupp gun. Shell fully charged with dynamite were fired without accident, using very small powder charges, but when the latter was increased to 1.65 pounds, the shell burst in the bore:

Two shells were successfully fired during the siege operations of the 2d Corps of the Army of Versailles (1871), one from a 24-pounder howitzer, the other from a mortar. The dynamite was enclosed in a rubber bag held in position with gunpowder, and was ignited by time fuses.

In 1874 Commander Barker, U. S. Navy, fired without accident of any kind at the Torpedo Station, nine shell charged with dynamite from a 24 pounder howitzer. Full service charges of gunpowder were used, and all service conditions as to the shell were observed. Three of the shell were unfused and were fired into the wall of an old bomb proof, exploding upon impact. The remaining six were fused (Bormann) and fired up the bay, none exploding prematurely and some of them at the fixed time. In 1884 experiments were made with firing dynamite from powder guns, using a special form of shell designed by Mr. F. H. Snyder.

The shell consisted practically of a sabot, built up of gelatinized fibre, leather and copper disks placed next to the powder charge; next came a brass case containing a cellular rubber

buffer, and then a wooden plunger for compressing the buffer, and finally the magazine for holding the dynamite.

These shell proved unsuccessful at the time, although the inventor claims to have overcome the difficulties and to have successfully fired shell charged with five pounds of dynamite. During the same year Commander Folger, U. S. Navy, fired 22 shell, each containing  $5\frac{1}{2}$  ounces of dynamite from a 12-pounder (10 rounds being fired under service conditions), the only precaution taken in loading the shell being a little oakum introduced as a packing.

In 1886 a shell designed by Mr. J. W. Graydon (at that time Lieutenant, U. S. Navy) was tested at the Presidio, San Francisco; 52 unfused shell containing dynamite No. 1 being fired from a  $4\frac{1}{2}$ -inch siege gun, using the service powder charge. These experiments were conducted before a Board of U. S. Army Officers appointed to investigate and report upon the invention, and were so successful, that the board unanimously recommended that the trials be continued with the 8-inch converted M. L. Rifle and the 15-inch smooth bore gun.

The shell was loaded and prepared for firing as follows:—It was first lined with asbestos paper, two thicknesses being placed on the bottom, and the dynamite was then introduced in paraffined packages and rammed with wooden rammers until the shell was filled. Between the base of the projectile and the powder charge were inserted eight asbestos wads. Experiments with this system were continued the following year by the Army Ordnance Board at Sandy Hook.

A 7-inch Ames M. L. Rifle was used, and steel shell weighing 122 pounds, containing 2.3 pounds of dynamite No. 2, were fired with powder charges of 23 pounds. These shell were fused and filled with base-plugs for convenience in loading. Seven shots were successfully fired at a section of a wrought-iron monitor turret at the distance of 110 yards.

**Experiments with Shell charged with Explosive Gelatine.** In 1883 an Ordnance Board, U. S. Army, fired from the 3-inch wrought-iron field gun five shell, each charged with  $6\frac{1}{2}$  ounces of explosive gelatine, and fitted with Schenkle percussion fuses. All



the shell burst after leaving the gun and before reaching the target. The explosive had been on hand for some time. These experiments were continued during the same year, the same gun, but a new lot of Nobel's explosive gelatine and new projectiles being used. The first shell broke up on leaving the gun, and the second struck the target sideways and broke in pieces. Five other rounds were fired and all of them broke up prematurely. It was thought that the want of success was due to the heat generated by friction, between the rotating projectile and the explosive, therefore three projectiles were made for trial with the 3.2-inch gun, in which the difficulty was avoided but with no greater success.

Further experiments were conducted with the 8-inch converted M. L. Rifle. New cast-iron projectiles were made, having ogival heads which were connected to the body by means of screw threads. To avoid friction between the explosive and the walls of the projectile, the explosive was packed in a paste-board cylinder divided longitudinally into four compartments by two pieces of wood. The cylinder fitted the shell loosely, and was coated on the exterior with plumbago and tallow. The shell contained about five pounds of explosive gelatine, and the powder charge consisted of forty pounds of Dupont S. H. powder. Between the gunpowder charge and shell was interposed a hollow rubber buffer six inches long and one inch thick. The first and third shell broke up on impact, the second separating as it left the gun.

A new shell was next made and tested. In it the explosive was made to revolve with the projectile by means of a copper diaphragm let into grooves cut into the interior walls of the shell. This shell proved successful, but a heavier and stronger steel shell with a solid head and heavy screw base-plug destroyed the gun. At first this accident was attributed to the fact that the gelatine was old and uncamporated, but a second round in which new camporated gelatine was used also burst in the muzzle of the gun.

It is but fair to observe, however, that during these trials, three Butler shell charged with gunpowder and fused with fulminate fuses, broke in precisely the same manner as did those containing gelatine. Subsequent experiments with explosive gelatine as a

bursting charge for shell fired from powder guns, have proved equally unsuccessful.

**Experiments with Shell charged with Hellhoffite.** The principle employed in using high explosives as a charge for projectiles, is applicable to explosives of the Sprengel class as well as to those already enumerated. As applied to this special class of explosives, it consists in placing the ingredients in the shell in separate vessels of glass, porcelain or similar material, which are strong enough to resist the jolts and jars incident to transportation and handling, but which are broken by the shock of discharge in the gun; or it may be done by dividing the shell into compartments by suitable diaphragms. When the first method is used the vessels are encased in rubber, felt, or other elastic material before being introduced into the projectile.

In his earlier experiments with hellhoffite, Gruson placed the nitric acid in the head of the projectile, and the dinitrobenzene in the base. When explosion after penetration was required, the ingredients were placed in reverse order, and a delay-action fuse in the base retarded the operation of the mixture until the point of greatest penetration had been attained.

In 1883 six 15-cm. shell, each containing 1.1 kg. of hellhoffite, were fired against a parapet. The damage done amounted to four times that effected by a like number of shell charged with gunpowder and fired under similar conditions. In 1884 twelve 15-cm. Gruson shell, each containing 1.9 kg. of hellhoffite, were fired at Palmanova with 1.2 kg. of gunpowder, and four rounds with 1.4 kg. of powder. Subsequently three 24-cm. shell charged 5.53 kg. of the same explosive, were fired with 4.2 kg. of powder. There were no premature explosions, but, aside from the inaccuracy of the projectiles, the effect was less than that of similar shell charged with gun-cotton, although greater than that of shell charged with gunpowder.

**Experiments with Shell charged with Melinite.** During recent years the attention of all military powers has been attracted

by the experiments with mélinite, conducted by the French Government, but in the majority of trials, the authorities have succeeded in maintaining a strict secrecy. The results of the *Belliqueuse* experiments are well known. Although but little effect was produced by the mélinite charged shell on the armored portions of the vessel, the destruction wrought by the shells which penetrated the unarmored parts was so terrible as to cause the naval experts to recommend that all unfinished vessels be protected by complete armor in order to resist the fire of all such projectiles.

The fire directed against the *Belliqueuse* was from 14-cm. and 16-cm. guns of the model of 1881, and the shell, weighing 66 and 99 pounds, were charged respectively with 6.2 and 8.8 pounds of mélinite.

Dumas-Guilin states that shell containing 33 kg. of mélinite have been fired at Bourges, and that the effect produced by mélinite shell is fully equal to that produced by the Germans with gun-cotton shell. Recent reports claim that mélinite shell have been repeatedly and successfully fired from high power powder guns under service conditions, with velocities as high as 2000 feet per second, and it is an established fact that charges of nearly 70 pounds have been fired from 22-cm. mortars, with velocities exceeding 1300 feet per second. According to Professor Munroe, from whose excellent course of lectures I have so largely borrowed in the preceding pages, we are more likely to find the high explosive for use in shell among the nitro-substitution compounds, than among the nitric esters.

## LECTURE XXIII.

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### EXPLOSION BY INFLUENCE OR SYMPATHETIC EXPLOSION.

In considering the various theories which have been proposed by investigators in explanation of the phenomena attending the explosion of different explosive substances, the subtlety and plausibility of their reasoning together with the originality and delicacy of their experiments, lead us to overlook certain well known and generally accepted facts.

Both explosion and detonation may be considered as but different phases of the common and daily occurring phenomenon known as combustion, in which the element of time varies between very wide limits.

We are well aware of the fact that the application of heat, directly or indirectly, is the principal means of producing an explosion, and this is equally true in the case of combustion and detonation. It has been pointed out that the mode of producing the heat also exercises a very important influence upon the nature or the explosive reaction, so much so in fact, that it is possible to cause the same explosive to burn, explode, or detonate, according to the circumstances attending the transformation.

**Explosion by Influence or Sympathetic Explosion.** Detonation has been defined as the instantaneous explosion of the whole mass of a body, and it is a peculiarity of a detonating explosion, that when produced in a body it *may* induce a similar explosion in another portion of the same body, either when in contact with it, or even when only near it, but not in contact. In fact, it may induce such an explosion when separated from the second portion by means of a glass or metal plate, or even a mass of water, so that no heated or ignited particles can be projected from one to the other. This secondary explosion has been termed *sympathetic explosion or explosion by influence*, and has been deeply investigated by several eminent scientists.

**Abel's Investigations.** Abel has shown that, not only would a detonating body cause the detonation of another mass of the same body, but that it would cause also the detonation of other bodies. For instance, by detonating mercury fulminate in contact with gun-cotton or nitroglycerine, these bodies were also readily detonated. Only a small quantity of fulminate was required, 0.32 of a gram (5 grains) when confined in a sheet metal cap, and placed in direct contact with the nitroglycerine or compressed gun-cotton being sufficient to cause the detonation of the latter.

He found that a mass of nitroglycerine by its explosion, would cause the explosion of another mass of nitroglycerine, even though both were immersed in water. His experiments further showed, that a peculiar kind of detonation was required in order to cause the detonation of an explosive. For instance, while the detonation of gun-cotton would cause the detonation of nitroglycerine in close proximity to it, the detonation of nitroglycerine would not cause the detonation of gun-cotton.

This shows that this property of causing detonation does not depend alone upon the force of the detonator, for we know that nitroglycerine is more powerful than gun-cotton. Again, silver fulminate, which explodes more violently and sharply than mercury fulminate, and nitrogen iodide, and nitrogen chloride, which are the most violent explosives we possess, are very much less efficient in causing detonation than mercury fulminate. In the course of his investigations, Abel was led to the conclusion "that a particular explosion or detonation may possess a power of determining at the instance of its occurrence, similar violent explosions in distinct masses of the same material, or in contiguous explosive bodies of other kinds, which power is independent of, or auxiliary to the distinct operation of mechanical force developed by that explosion; that as a particular musical vibration will establish synchronous vibrations in particular bodies while it will not affect others, and as a chemical change may be wrought in a body by its interception of only particular waves of light, so some kinds of explosions or powerful vibratory impulses may exert a disturbing influence over the chemical equilibrium of certain bodies, resulting in their sudden disintegration, which other ex-

plosives that develop equal or greater mechanical force, are powerless to exercise.

**Abel's Theory of Synchronous Vibrations.** Abel offers the following as being the most satisfactory explanation of the remarkable differences pointed out :

"The vibrations produced by a particular explosion, if synchronous with those which would result from the explosion of a neighboring substance, which is in a state of high chemical tension, will, by their tendency to develop those vibrations, either determine the explosion of that substance, or at any rate greatly aid the disturbing effect of mechanical force suddenly applied ; while in the case of another explosion which produces vibrations of a different character, the mechanical force applied by its agency has to operate with little or no aid ; greater force or more powerful detonation must, therefore, be applied in the latter instance, if the explosion of the same substance is to be accomplished."

That vibrations will induce the decomposition of chemical compounds, whose atoms are in a state of unstable equilibrium, is a fact too well established in science to be dwelt upon.

**Investigations of Champion and Pellet.** This theory was examined experimentally by MM. Champion and Pellet. They took a tube seven metres long, made in two lengths and joined by a paper band. Small quantities of nitrogen iodide were placed in each end, and when one was exploded it immediately caused the explosion of the iodide at the other end, but, if the paper band connecting the two lengths was removed, the second explosion did not occur. By a suitable apparatus it was shown that the effect produced was not due to the action of a puff of air, but to vibrations of the air such as are caused by a sounding body. When nitrogen iodide was attached to the strings of a double bass and the string was bowed, the iodide exploded when placed on the string giving the highest rate, but not when on the two lower strings. The lowest number of vibrations which would cause explosion was found to be thirty per second.

Similar results were obtained with other musical instruments. A further set of experiments was made to determine the difference between the vibrating motion excited by various detonants,

and thus to account for the differences in their ability to provoke, by means of the intervening air, the explosion of other detonants placed at a distance. A series of sensitive flames was arranged, corresponding to the complete scale of G major, and 0.03 grams of mercury fulminate excited the *a*, *c*, *e*, *f* and *g*. A like quantity of nitrogen iodide when exploded under similar conditions produced no effect. This showed that the vibrations excited by the two explosives were very different, and also that the vibrations excited by the mercury fulminate act on flames belonging to some notes of the scale to the exclusion of others.

On exploding these substances nearer the flames than in the former experiment, while the nitrogen iodide excited only flames corresponding to the higher notes of the scale; the mercury fulminate affected them all. In these experiments it was observed that acute sounds predominate in explosions.

The same investigators took conjugate parabolic mirrors, covered their surfaces with lamp-black so as to prevent the reflection and concentration of heat rays from them, placed them 2.5 metres apart, and distributed small masses of nitroglycerine and of nitrogen iodide at different points along the line of foci. They then detonated a large drop of nitroglycerine at one of the foci, and observed that the substances placed in the corresponding conjugate focus detonated, but that the rest remained unaffected. This same line of investigation was continued by Abel, who claimed that his results tended to confirm his theory.

**Berthelot's Investigations.** Berthelot contended that not only were these experiments inconclusive, but, from his point of view, several of them appeared directly opposed to Abel's theory. He noted in the first place that the characteristic feature of the given musical note, which is capable of determining each variety of explosion had never been established; that it was only below a certain note that the effects ceased to be produced. While the various explosive substances, almost without exception, proved particularly sensitive to the action of the most acute notes. Moreover these effects ceased to be produced at distances which were incomparably less than the resonance of the chords in unison, and this fact, he claimed, proved that the detonations were functions of the intensity of the mechanical action, rather

than of the character of the determining vibration. Similarly, the detonation ceased to be produced when the weight of the detonating substance was very slight, and when in consequence the mechanical energy of the shock was greatly weakened. Yet, if the theory of "synchronous vibrations" were true, the specific vibratory note which determines the explosion should always remain the same. For instance, cartridges filled with dynamite No. 1, cannot be detonated by a cap containing less than 0.2 gramme of fulminate, and the detonation is assured only when the detonator contains one full gramme of the fulminate.

This, the investigator claims, establishes the fact of the existence of a direct relation between the character of the detonation, and the intensity of the shock produced by one and the same detonating substance.

If it be true that gun-cotton will cause the detonation of nitroglycerine in consequence of the synchronism of the vibration communicated, then the effect of these substances upon each other should be reciprocal, and the failure of nitroglycerine to detonate gun-cotton, therefore, is due to the difference in the structure of the two substances, which plays a very important part in the transformation of the mechanical energy into work. This diversity of structure and the modifications which it causes in the transformation of the phenomena of the shock, and the transformation of the mechanical energy into thermal energy, may be cited to explain the facts observed by Abel.

All the effects observed with nitrogen iodide may be explained by the vibration of the supports and by the friction resulting therefrom. The experiment with the conjugate mirrors may be explained by the mechanical effects resulting from the movement of the air when concentrated in the focus. Moreover, M. Lambert has shown experimentally, that in the explosion of dynamite cartridges in cast-iron tubes of large diameter, regarded from the standpoint of detonation by influence; there does not appear to be any difference between the ventral segments and the nodes characteristic of the tube. To clear up this matter by eliminating the influence of the supports, and the diversity existing in the cohesion and physical structure of the solid explosive substances used, Berthelot undertook a series of



experiments on the chemical stability of matter in sonorous vibration, and especially on that of gaseous bodies such as ozone and hydrogen arsenide, or liquids such as hydrogen peroxide and persulphuric acid ; all of these bodies being selected from among those which decompose with the disengagement of heat, precisely as explosive substances do.

The experiments were made by enclosing the substances in glass vessels which were attached to one arm of a tuning fork, which vibrated at the rate of one hundred single vibrations per second, or by enclosing them in a glass tube which by means of a rubber, was made to give 7200 single vibrations per second. The substances were analyzed, and then subjected to the vibratory action for periods varying from one-half to one and one-half hours and then analyzed again. In no case had there been any notable decomposition, whence the investigator concluded that endothermous bodies were stable under the influence of sound waves, but were decomposed under the influence of ethereal vibrations.

**Berthelot's Theory.** From the consideration of these facts, and especially from experiments made in firing under water, Berthelot concluded that *explosions by influence, like detonations in contact, were due to the transmission of a shock*, arising from the enormous and sudden pressure by the explosive, which is converted into heat within the explosive material itself. Thus, in the extremely rapid reaction which obtains, the pressures produced may approach to the limit which corresponds to the matter detonating in its own volume, and the commotion due to this sudden development of almost theoretical pressures can be propagated through the ground and supports as intermediaries, or through the air itself, being projected *en masse*, as has been shown in the explosion of certain powder factories and gun-cotton magazines, and in some of the experiments made with dynamite and compressed gun-cotton.

The intensity of the shock propagated, either by a column of air or a liquid or solid mass, varies with the nature of the explosive body and its mode of inflammation ; it is of greater violence according as the duration of the chemical reaction is shorter and

develops more gas, that is to say, a higher initial pressure and more heat, and consequently more work for the same weight of explosive material. This shock is transmitted better by solids than by liquids, better by liquids than by gases ; with gases it is better as they are more compressed. Through solids it is better propagated according to their degree of hardness. All breaks of continuity in the transmitting material tend to weaken it, especially if a softer substance is interposed. Thus it is, that the use of a tube made from a goose-quill as a receiver, stops the effect of mercury fulminate, while a tube or a capsule of copper transmits this effect in all its intensity.

Explosion by influence is the better propagated in a series of cartridges, according as the envelope of the first detonating cartridge is the more resisting, as it thus enables the gases to obtain a greater pressure before the covering is destroyed.

The existence of an empty space, that is to say, one filled only with air between the fulminate and the dynamite, diminishes the violence of the shock transmitted, and in consequence that of the explosion, and in general the effects of violent powders are lessened when there is no contact.

To form a full conception of the transmission by the medium of sudden pressures which produce shock, it is desirable to recall the general principle, in virtue of which pressures are transmitted in a homogeneous mass equally in all directions, and are the same on any small element of the surface, whatever its position. Detonations produced under water with gun-cotton, show that this principle is equally applicable to the sudden pressures which produce explosive phenomena. But it ceases to be true when one passes from one medium to another.

If the inert chemical matter which transmits the explosive movement is fixed in a given situation like the surface of the ground, or better still, held by the pressure of a mass of deep water, in the midst of which the first detonation is produced, the propagation of the movement in this medium will hardly be able to take place, except under the form of a wave of purely physical order, and consequently of an essentially different character

from the original wave which is developed in the explosive body itself, and which is of a chemical and physical order. Whilst the first wave which is of a chemical order, is propagated with a constant intensity, the new wave which is of a physical order, transmits the concussion away from the explosive center all around it, with an intensity which decreases inversely as the square of the distance. In the neighborhood of the center of the explosion, the displacements of the molecules may overcome the cohesion of the mass and disperse it, or crush it by enlarging the explosion chamber, if the operation is conducted in a cavity. But, at a very short distance (the magnitude of which depends on the elasticity of the surrounding medium) these movements, confused at the beginning, arrange themselves in such order as to produce a wave, properly so called.

Characterized by compressions and sudden deformations of the material, the amplitude of these oscillations depend upon the magnitude of the initial impulse. They move with a very great rapidity, and preserve their irregularity up to the point where the continuity of the medium is interrupted; then these compressions and sudden deformations change their nature, and are transformed into a movement of impulse, that is to say, they reproduce the shock. If then they act on a new cartridge, they may determine its explosion; the shock will be otherwise weakened by the distance, and in consequence the character of the explosion may be modified. The effects diminish in this manner up to a certain point, from which the explosion ceases to produce itself. When this occurs with a second cartridge, the same series of effects will be continued from the second to the third cartridge; but this depends on the character of the explosion which the second cartridge undergoes. And thus it goes on.

Such is the theory that Berthelot offers to explain explosions by influence, and the phenomena which accompany them. It depends, definitely, on the production of two orders of waves, one series representing the explosive waves, properly so called, developed in the midst of the matter which detonates, and consisting of a continually reproduced transformation of chemical

actions into thermal and mechanical actions, which transmit the shock to the support and to the contiguous bodies ; the other being a purely mechanical and physical series, which transmits the sudden pressure equally about the center of the concussion to the adjoining bodies, and by a singular circumstance to a new mass of explosive material. As to the action within the original mass, he holds that the kinetic energy of the shock of the explosion (by the détonator) is transformed into heat at the point struck ; the temperature of this point is thus raised to the temperature of explosion, a new shock is thus produced which raises the temperature of the neighboring portions to the same degree ; they then explode and the action is propagated with an ever increasing velocity.

**Threlfall's Investigations.** Neither Abel's theory of synchronous vibrations, nor Berthelot's wave theory satisfied Threlfall, and he therefore made an experimental and critical study of the manner in which the explosive reaction is communicated from one explosive mass to another explosive mass through a non-explosive medium. Much might be learned from a measurement of the velocity of transmission of a shock, to points at small distances from the center of explosion. This would be merely a question of experiment, and Lord Rayleigh suggested the use of a sensitive flame and revolving mirror, which would, at all events, give some idea of the sort of disturbance experienced ; but Threlfall deemed it best to begin by examining cases where the results of explosion could be seen and watched. For this purpose he constructed a tank measuring a yard each way, and provided with windows in the sides. The tank was filled with water, and water-tight glass bulbs of one-half inch diameter, filled with mercury fulminate, were sunk to the depth of eighteen inches in the water, fired by electricity, and the course of the debris from the explosion noted. As the torpedo was suspended vertically, this debris had the appearance of being shot down to the bottom of the tank—not in a jet as might have been expected, but with exactly the rolling motion that smoke has in coming out of a chimney, as if in fact, there was vortex motion of some sort.

The constancy of the downward action of the explosion suggested that it was due to the want of symmetry introduced by the neck and wires of the torpedo. Hence, experiments were made in which the torpedoes were placed horizontally, and then the debris seemed to move with its peculiar rolling motion, horizontally away from the neck. In fact, the appearance presented to the unaided eye was that of a more or less definite column of rolling white smoke shot out with great velocity, and coming to rest very rapidly when about five inches from the center, as if acted upon with an irresistible force. Experiments were also made by exploding a charge in the center of a Florence oil flask, filled with red dye and immersed in the water. The dye was shot out with the debris, and the flash appeared to be suddenly stopped some two or three inches outside where the flask would have been if it had not disappeared. There were, however, so many sources of misinterpretation to be feared in this method of observation that it was not continued, but the experimenter contented himself with noting the peculiar rolling motion of the dye as it was shot out.

Experiments were now made to determine if the directions of projection of the debris coincided with the directions of propagation of the stream of explosive energy. For this purpose a pendulum gauge was devised which was fitted to the tank, and by firing some dozen torpedoes arranged as symmetrically as possible, he found that the indications of the gauges were nearly proportioned. Explosions were then produced in torpedoes purposely made unsymmetrical, either by having the glass too thick on one side, or by turning up the ends of the covered conducting wires, so that they entered the bulb horizontally and facing one of the gauges.

The effects now became more puzzling, but on the whole there was no question but that the gauge towards which the bulb was turned suffered most. In fact, the direction taken by the streams of explosive energy, appeared to coincide with the directions of projection of debris, and with the direction foretold from the initial conditions. The experiments were repeated at various distances, and in various manners with more or less compressed charges, and with variations in the position of the firing point.

The pendulum readings were on the whole proportional to the direction of explosion as foretold from the initial conditions.

Of course, in some few cases, there were unexpected actions on the gauges, but this was hardly avoidable, since the previous experiments had shown how small a change in initial conditions could lead to great variations in the result. The position of the firing-point was the least satisfactory part of the experiments, most of the failures could be traced to imperfect centering of the firing-point; about ten per cent. of the experiments failed to travel on the paths laid out for them. These experiments leave little doubt that the direction in which the maximum explosive effect is transmitted, will in a great measure depend on the initial arrangement of surrounding obstacles; at all events, when the explosion is caused by fulminate of mercury and small charges are used, In fact, the shock of an explosion must be transmitted in one or more of three different ways:

1. By actual bodily motion of the products of explosion through the surrounding medium, either alone or becoming more and more mixed up with the medium itself, which is thereby set in motion.
2. By an undulating motion set up in the medium.
3. By vortex-ring motion.

In the explosion of gunpowder and other slow explosives, the energy is transmitted chiefly by 1 and 2. The distance to which a considerable quantity of the energy may be conveyed by means of waves of comparatively great amplitude, is in some cases remarkably great. This is evidenced by the effects produced by the explosion of powder magazines.

In the case of the fulminates of mercury and silver, gun-cotton and nitroglycerine, that is, explosives of the class examined under water, the effect falls off very rapidly with the distance, and in water at all events, is of a directed character. This would point to the third mode of transmission being in these cases of some importance, and if we consider the way in which the products of explosion escape, we shall find that the conditions for the production of vortex motion do exist. Let there be a sphere of mercury fulminate fired from its geometrical center, then by

Vieille's experiments on the time of explosion, it seems likely that the outer portions of the fulminate will be decomposed before they are removed to any appreciable distance from their original positions.

We shall therefore have a sudden expansion in all directions, caused by the increase in volume of the explosive substance during the explosion. There seems no reason why, under perfectly symmetrical conditions, the expansion should not go on as it began until the cooling of the sphere of hot gases becomes so marked as to prevent further expansion. If the conditions, however, are not such as to allow of symmetrical expansion, which occurs in practice, then we shall have the bounding surface of the explosion gases more curved in some places than in others, that is, the strain will be greater at some parts than at others, and in fact may become so great at points of greatest curvatures as to lead to a state of "breakdown." In other words, the compressed gases in this case escape, not by gradual expansion, but by jets, from points whose positions are fixed by the conditions of explosion. In these jets we should have the necessary and sufficient conditions for the establishment of vortex motion. If vortex motion were set up, then it seems likely that much greater effects might be transmitted in some directions than in others, though at considerable distances the effects would tend to become uniform in all directions. Threlfall believes that this view of the actions of explosions will enable us to explain several difficulties occurring in the interpretation of Abel's experiments. Among these are:—The want of correspondence between the explosive actions, as measured by the effect produced on copper plates, and the effects produced in causing explosions; the apparent capriciousness of explosions of the more violent kinds; and finally the production of explosions by influence.

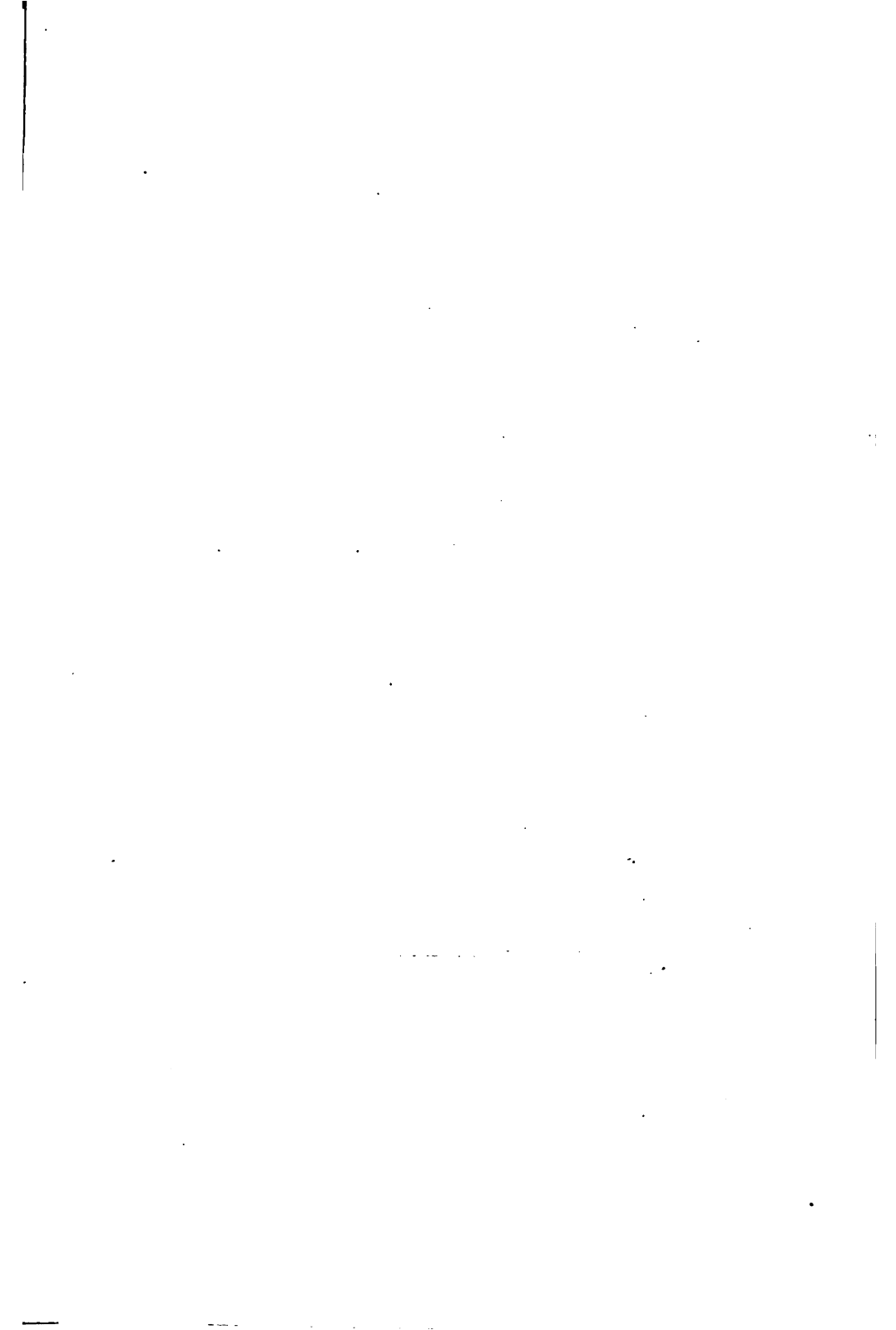
The investigations of these eminent scientists, and the theories advanced by them in explanation of the observed phenomena, have been ably reviewed by Professor C. E. Munroe, Chemist to the U. S. Naval Torpedo Corps. While recognizing the plausibility of the theory advanced by Berthelot, and admitting that his views are in a measure supported by experiments, Professor Munroe is unwilling to accept this theory in its entirety. In fact,

he rather inclines to Abel's theory of "synchronous vibrations." Touching the investigations of MM. Champion and Pellet, the only points noted refer to the explosive substance used in their experiments—nitrogen iodide—and the peculiar conditions under which the experiment with mirrors was performed. In the first case, the only cause for surprise or wonder is that the investigators were able to find a string that would vibrate sufficiently slowly not to fire the iodide; while in their efforts to establish the theory of synchronous vibrations by the mirror experiments, they proceeded to coat the surfaces of the mirror with a material (lamp-black) which would absorb the vibrations, which upon this theory, would be most active in producing the desired effect.

In conclusion, he claims that if the synchronous vibrations can be disproved at all by experiment, then Abel himself has contributed the strongest evidence against it. In the light of what has been published on the subject, there is sufficient reason for hesitation in accepting Abel's theory. On the other hand, if the vortex motion be accepted, several otherwise apparently inexplicable phenomena are readily accounted for. The most important effect to be explained is the capriciousness of explosions, such as was exemplified in the Bremerhaven disaster, where those in the vicinity of the explosion seemed picked out for injury, and that too not by the scattered debris alone. These effects are almost inexplicable upon any theory of uniform wave motion, or upon any other theory than that based upon the coexistence of the two states of propagation, that of wave motion and that of vortex motion.

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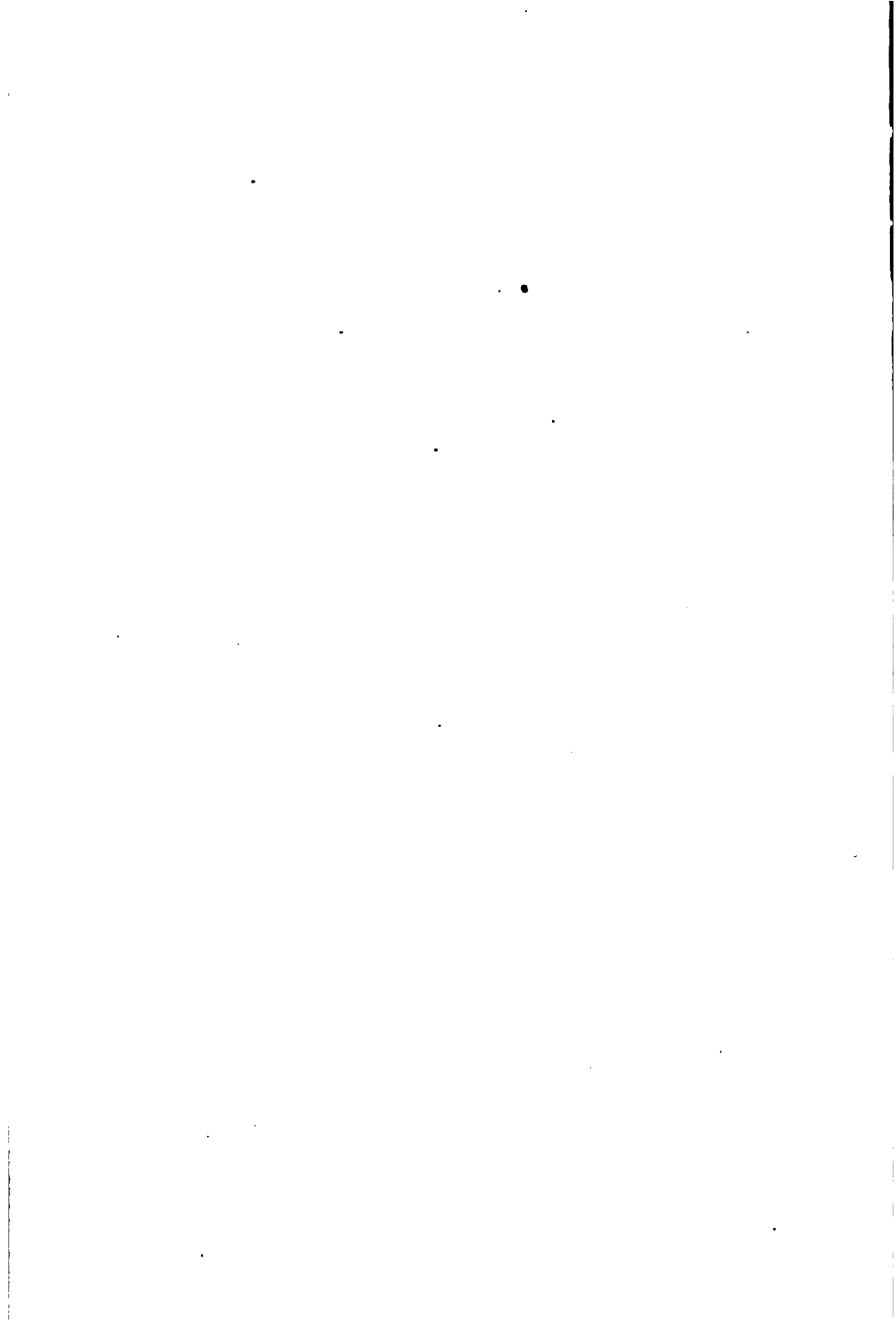
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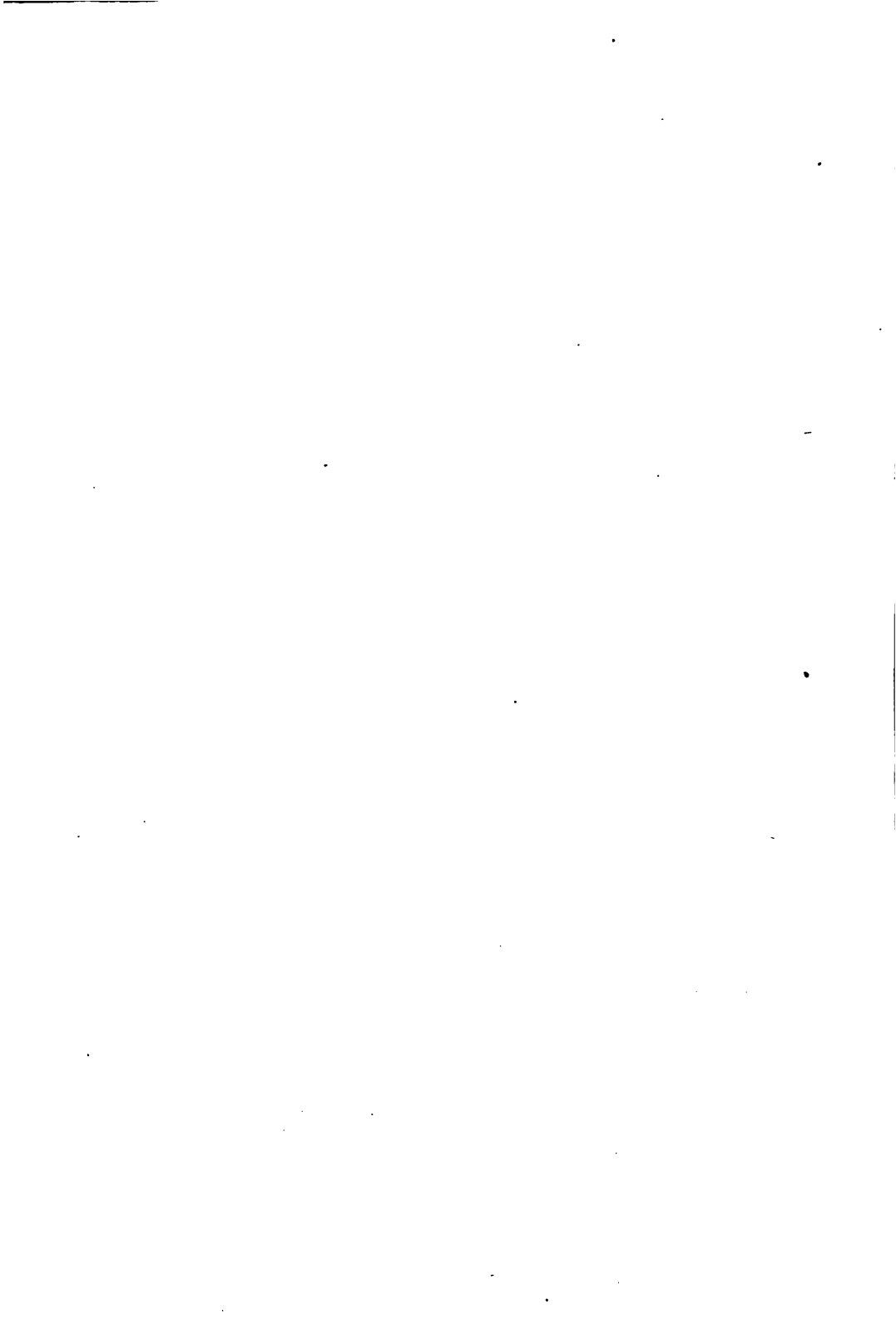
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